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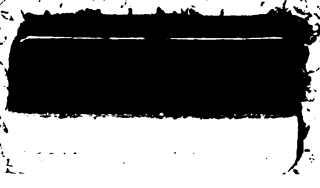

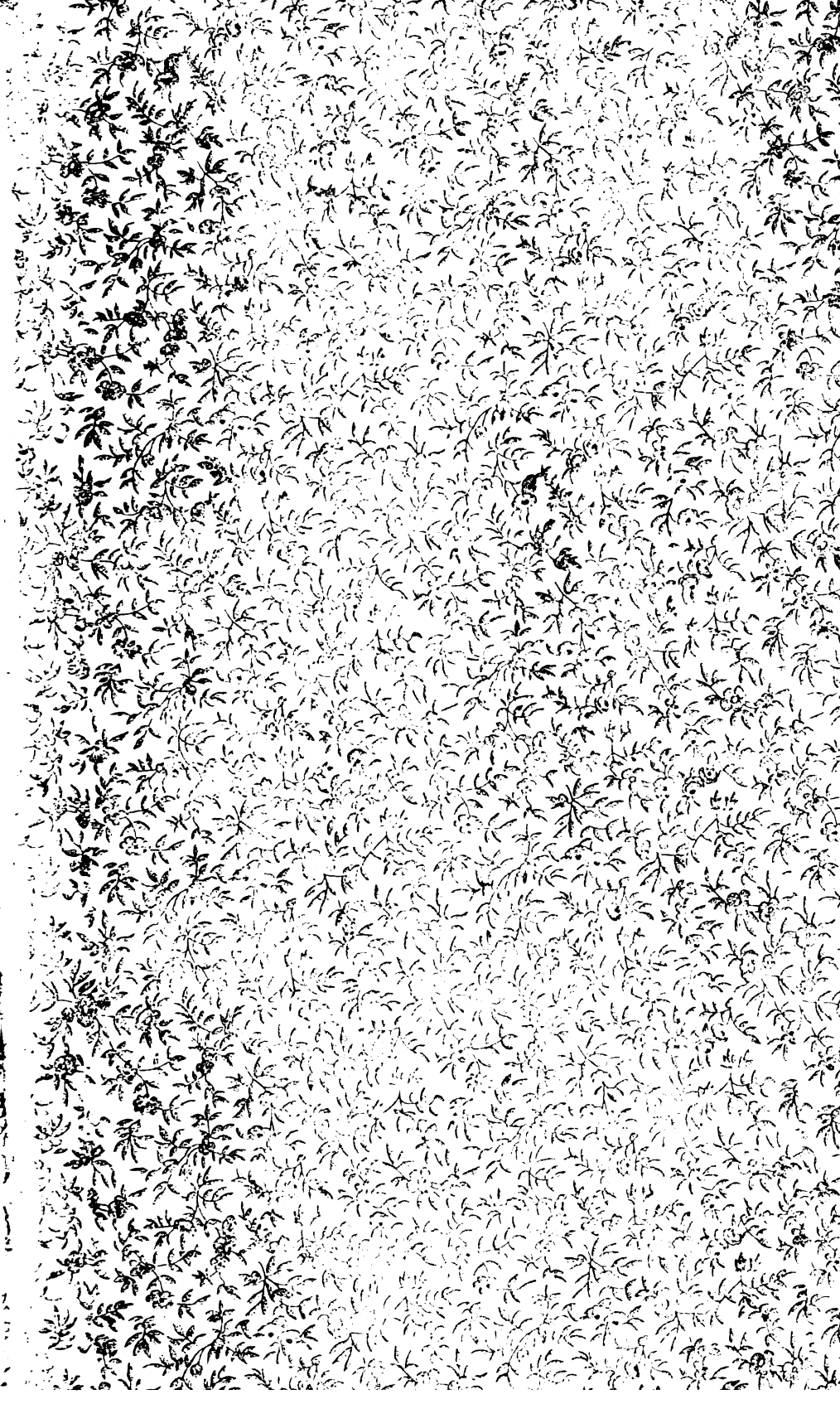

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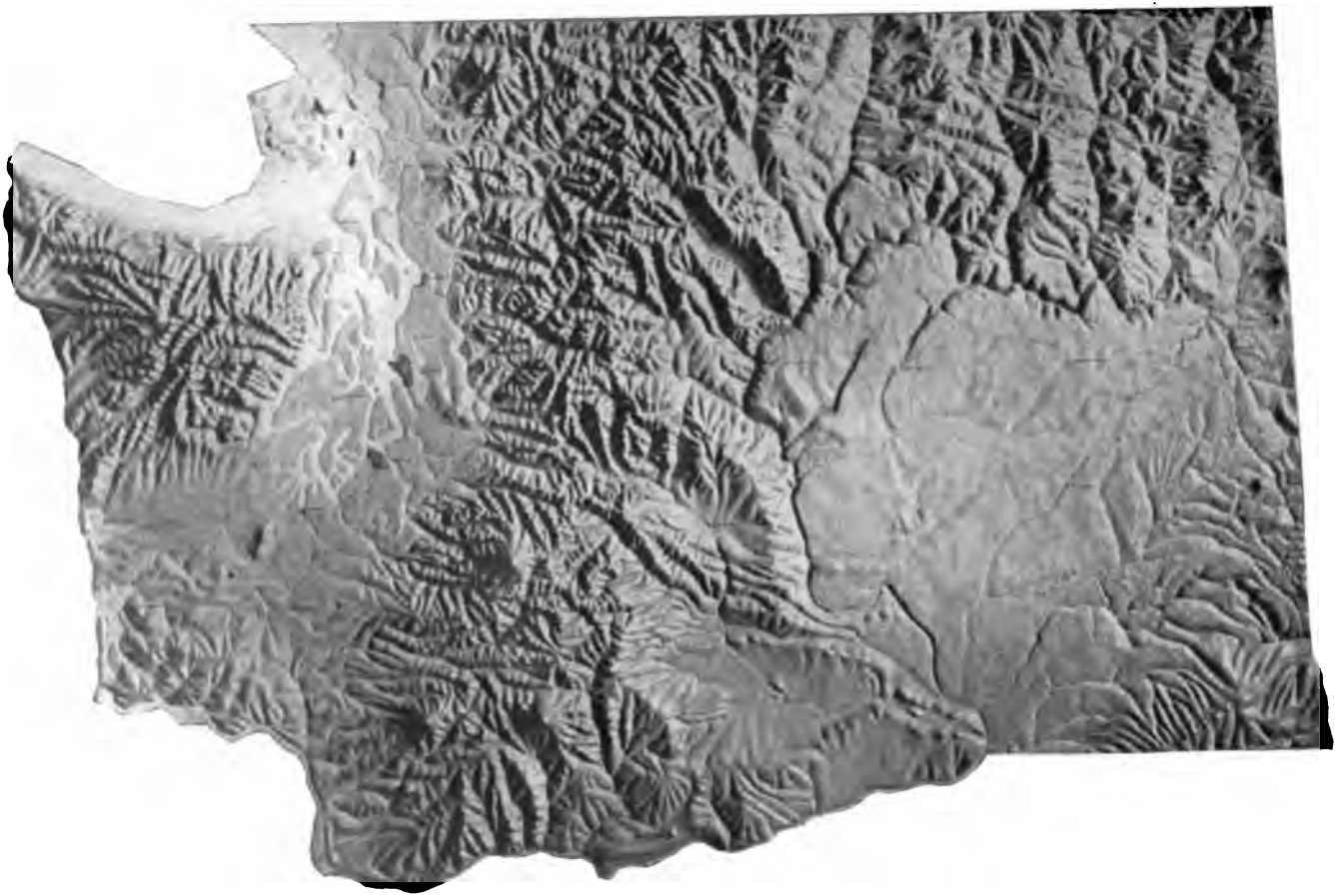

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RELIEF MAP OF WASHINGTON, BY SOLON SHEDD

THE CLAYS OF THE STATE OF WASHINGTON

THEIR GEOLOGY, MINERALOGY, AND TECHNOLOGY

By SOLON SHEDD, Ph. D.
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STATE COLLEGE OF WASHINGTON

PULLMAN, WASHINGTON
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M. N. D.

PREFACE.

Work on the clays of Washington was begun in the summer of 1901 while working on the Washington Geological Survey, small part of the field season that year being devoted to this work. Some of the most important clay deposits and clay-working plants were visited and samples of the clays procured and sent to the State College for study. On account of other work, nothing further, however, was done until the summer of 1903, when, on account of the Washington Geological Survey having been discontinued, the State College took up the work and has furnished the means for completing it.

Field work has been carried on during a part of each of the summers of 1903, 1904, 1905, and 1906; the different localities where the clays are being utilized having been visited, samples of the clays procured, and the deposits studied. Samples have been obtained also from many deposits which up to the present time have not been utilized. For various reasons, however, it has not been possible to visit some localities where clays that are suited to the manufacture of certain kinds of clay products may occur. In some cases samples have been procured from these localities by giving the party interested in the deposit directions in regard to sampling and having samples taken by him and sent to the College.

Chemical analyses and physical tests have both been made on the clays and the results are given in this report. A general discussion of clays, in which the chemical and physical properties are treated quite fully, is also given in the hope that it may be of value to the clay workers of Washington.

It is my hope that the investigation of the clays, the results of which are given here, may aid in the development of the clay

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industries of Washington and increase the variety of the clay products.

I take pleasure in here acknowledging the many courtesies received from the clay workers in various parts of the state. In practically every case they have been very willing and glad to aid in every way that they could. To President E. A. Bryan I am especially indebted, as without his assistance it would not have been possible to do this work. To Professor W. R. Bloor, who made most of the chemical analyses given in the following pages, I am indebted on account of his very careful and painstaking work. To Dr. J. C. Branner and Dr. J. P. Smith, both of Stanford University, I am under obligations for valuable suggestions in regard to the work.

Acknowledgments are due to the various manufacturers of clay-working machinery for the loan of cuts used in illustrating this volume as listed below; to Mr. A. Abrahamson for photographs of his brick plant; to Mr. J. R. Miller for photographs of the Denny-Renton Clay and Coal Company's clay-working plants at Taylor, Renton, and Van Asselt; to Mr. J. R. Spear for photographs of the Washington, Brick, Lime and Manufacturing Company's plants at Clayton and Freeman.

In this volume an effort has been made to include all available facts from reliable sources bearing on the subject of clay that it was thought would be helpful in a correct understanding of the value of the deposits in Washington. Reports of State Geological Surveys and technical treatises have been freely consulted and data taken from them. Credit for such information is given in each case in the foot note references, but I desire also to make a general acknowledgment here.

Acknowledgments are due the city engineer's office of Seattle for results of physical tests of Denny-Renton paving brick; also Mr. Geo. W. Evans, who was for a number of years Deputy County Surveyor of King county and at present Geologist in charge of coal surveys for the Washington Geological Survey, who has helped me in various ways.

S. Shedd.

State College of Washington,
Pullman, Sept., 1909.

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PART I

CLAY AND ITS PROPERTIES

CLAYS AND CLAY INDUSTRY OF WASHINGTON

CHAPTER I.

CLAY AND ITS MODE OF OCCURRENCE.

Clay is one of the most abundant substances of economic importance found in nature. It is very widely distributed geographically, occurring in some form in almost every locality. On account of certain properties which it has it is capable of being used for a great many different purposes, and for this reason it came into use at a very early date, in the development of the country, in many forms and for different purposes. The uncivilized inhabitants of the world have found it useful in the construction of their rude dwellings and for forming utensils and vessels of different kinds for various uses. Some of the many uses to which clay is put by the highly civilized nations of the world are mentioned and described more fully in the following pages.

Definition.—The term clay as generally used is a very broad one and includes a very lage variety of substances, all of which, however, when mixed with water, become more or less plastic and capable of being molded into various shapes, which are retained when dry, and if heated to redness, or higher, the material becomes hard and rock-like. The substances which are included under the term clay will vary much in both chemical and mineralogical compositions. The varieties differ widely in their physical characteristics also. From the above it seems that there are many kinds or varities of clay, and in fact so great is the variation in the material classed under this head that no brief general definition that is at all satisfactory can be given.

*Merrill, in his discussion of the subject of clays, says they

*The Non-Metallic Minerals, p. 217.

may be described, "as a whole, as heterogeneous aggregates of hydrous and anhydrous aluminous silicates, free silica, and ever-varying quantities of free iron oxides and calcium and magnesian carbonates, all in finely comminuted condition." This definition of clay is based on its mineralogical composition and shows how the materials classed as clay may vary as far as their mineralogical composition is concerned, and if this varies the chemical composition probably will also vary.

As usually defined, the term clay includes a mixture of minerals, the base of which is kaolinite or kaolin. Professor Edward Orton* in his report on the clays of Ohio says: "Strictly speaking, however, the term applies to a single mineral, viz., silicate of alumina or koalinite." Then a little further on he says, "it is this material (meaning kaolinite) that makes the basis of all clays." Again clays are defined by Beyer and Williams†, "as a mineral mixture in which kaolinite is present in sufficient amount to impart to the mass its characteristics to a degree allowing of its use in the manufacture of clay wares." Wheeler‡ in his report on the clays of Missouri says: "The scientific definition of the term clay is: a more or less pure variety of the mineral, kaolinite, the hydrous silicate of alumina."

Now from the above definition of the term clay it is apparent that the presence of kaolinite has been considered as a very essential constituent of all clays. This, however, is being questioned at the present time by some, as is shown by the following:

"It may be said at the outset that the statement so frequently made to the effect that kaolinite or even kaolin is the basis of all clays is not yet well substantiated."||

The popular definition of a clay and the one that is perhaps of as much value as any to the ordinary clay worker is based on physical properties, and mainly plasticity. To the ordinary clay worker this is the property first considered, and the others are considered in determining the adaptability of a particular

*Geol. Survey of Ohio, Vol. VII, Part I, p. 46.
†Iowa Geol. Survey, Vol. XIV, p. 35.
‡Missouri Geol. Survey, Vol. XI, p. 17.
||The Non-Metallic Minerals, p. 221.

clay for a certain purpose. Taking plasticity as the property of prime importance, clay is defined by Reis* as follows:

"Clay is the term applied to those earthy materials occurring in nature, whose most prominent property is that of plasticity when wet."

Wheeler† also gives the following as the popular definition of a clay:

"Clay is an earthy material that becomes plastic when mixed with water."

From the foregoing it is plain that there is much variation in the use of the term clay. All through this report, however, the term clay will be used in a very broad sense and will include all of those earthy or stony substances which are being used in the manufacture of clay products.

ORIGIN OF CLAYS.

The clays are all of secondary origin and have been produced by the decomposition of the various kinds of rock composing the crust of the earth. The igneous rocks, however, on account of their composition, are by far the most important in the formation of clays and are really the primary source of all clays. As the sedimentary rocks are all products of decomposition of the igneous rocks the clays derived from them have come primarily from the igneous rocks. The igneous rocks are made up of a great many different minerals in greater or less amounts mingled together and held mechanically. When these rocks are exposed to the atmospheric agencies, such as rain, percolating water, freezing and thawing of included water, changes of temperature, and the wind, they are slowly decomposed and broken down. There are a number of minerals which are found in the igneous rocks that contain more or less clay substance, the most important being, however, the feldspars.

In order to trace the process of clay formation from one of these igneous rocks we will take the case of granite, a rock which is composed of quartz, feldspar and mica as the principal min-

*New Jersey Geol. Survey, Vol. VI, p. 3.
†Missouri Geol. Survey, Vol. XI, p. 17.

erals, with small quantities of magnetite, apatite, etc., with often a considerable amount of hornblende. As already stated, these minerals are held together mechanically and when a mass of rock of this kind is exposed to the atmospheric agencies, minute cracks form in it and it begins to decay. In this decay of the granite there are two classes of forces acting to bring about this change, those that act mechanically and those that act chemically.

As the granite is warmed during the daytime it expands, and at night when it cools it contracts, and as it will not all cool at the same rate, contraction will be different in different parts of it. This will produce strains in the mass, which repeated many times will eventually produce cracks in the rock. Then again the different minerals of which the rock is composed will expand and contract different amounts for the same amount of change in temperature. The minerals which compose a granite are held together by the interlocking of one with the other, and this unequal expansion and contraction continued long enough finally loosens these grains completely. Water fills the crevices in these rocks, on freezing expands, and in this way acts as a wedge to separate these rock particles, and even large masses may be broken off from cliffs by this means. Plant roots force their way into the cracks and crevices and, by expanding as they grow, help the action of the frost in breaking up the rock mass. These processes alone, if continued long enough, would finally reduce the rock to a mass of small angular fragments.

All the effects so far discussed are the result of the mechanical action of these different agencies. Water, however, acts in another way, and in a more important one as far as the formation of clay is concerned. Rain water has a certain amount of carbon dioxide, which it has taken up from the atmosphere, and this gives to the water an acid reaction. It has also absorbed a certain amount of oxygen, which it carries along with it. Then again, if it has come in contact with decaying organic matter it has taken up more or less ogranic acids. Water containing these substances in solution percolating through the crust of the earth comes in contact with the different minerals of which rock is com-

posed, and the result is that the oxygen and the acids attack many of these particles and change them into entirely new minerals, some of which are readily soluble, and hence are taken into solution by the water and removed. The result, then, of this percolating water is not only to cause the rock to break down into small particles, but also to remove certain parts of it, and in this way form a clay.

The minerals already mentioned as being the principal ones in the granite are effected very differently by the different weathering agents. The feldspar, which is a silicate of alumina with potash, soda, or lime silicate, is the most readily effected by percolating water. When water which has an acid reaction—and, as already stated, all meteoric water has—comes in contact with the granite the first effect is that the feldspar begins to lose its lustre and becomes a light colored mass, and as time goes on new substances are formed, some of which, as the potash, soda, or lime, are soluble. These are taken into solution and more or less completely removed, and the remaining part, the aluminum silicate, takes up water and forms kaolinite. The grains of quartz which occur in the granite are practically insoluble in this ground water, and about the only change that takes place in them is the breaking up into smaller particles, which is a purely mechanical process. The rate of decomposition of the mica will depend somewhat upon the kind of mica that occurs in the granite. If it is muscovite or white mica, it will resist weathering better than the dark colored micas, such as biotite. This is due largely to the fact that the dark colored ones contain iron in their composition, and this oxidizes readily.

From the above it is readily seen that if a granite composed mainly of quartz, feldspar and mica be subjected to the action of the weathering agencies, the result would be that the granite would be changed or converted into a mass of clay in which would be more or less sand grains and mica scales. In addition to this there might be more or less of the alkalies, depending entirely on how thoroughly the leaching process had been carried on; and if the mica had been one of the dark colored ones, or if there had been some hornblende present in the granite, as

there often is, there would be more or less iron mixed through the clay, with probably small amounts of other substances. This would be the case of a clay that occurs in place, that is, that occurs where the rock decomposed which formed it. In a case of this kind on the surface we would have a layer of soil mixed with more or less organic matter, below which would be a layer of true clay, and as we would dig deeper this would gradually change and become more sandy and the particles get larger until finally firm, undecomposed granite would be found. That is, we find gradations between the true clay on the surface and the solid, undecomposed rock below.

The elements of clay are found, to a greater or lesser extent, in all of the igneous rocks and in some of the sedimentary, hence kaolin will occur in all of the soils which have been formed by the decomposition of igenous rock and some sedimentary rocks, and to this fact is due the very wide geographic distribution of clay. In the case of sedimentary rocks, the character of the clay produced from them will depend, in many instances at least, on the character of the minerals, usually considered impurities, found in them. In the case of a limestone, for instance, if it is a pure limestone it will contain nothing but calcium carbonate, and this in the presence of water having an acid reaction would be completely dissolved and nothing left from which to form clay. Most limestones, however, contain other minerals mixed with the calcium carbonate, and when this is taken into solution, more or less completely, and removed, these other minerals, if insoluble, and many of them are, remain and the clay is formed from them.

CHAPTER II.

CLASSIFICATION OF CLAYS.

Many attempts have been made at different times to classify clays. The basis of these different classifications has varied much, in some cases being the origin, in others it has been the uses to which the different clays are put, in others, physical properties, while in still others it has been chemical and mineralogical composition. In none of these, however, has the classification been entirely satisfactory for all purposes. The following are a few of the different classifications that have been made.

Professor Edward Orton* made the following classification, which is based on composition:

HIGH GRADE CLAYS.

1. Kaolin.
2. China clay.
3. Porcelain clay.
4. Fire clay (hard).
5. Fire clay (plastic).
6. Potters' clay.

LOW GRADE CLAYS.

1. Argillaceous shale.
2. Ferruginous shale.
3. Silicious clays.
4. Tile clays.
5. Brick clays.
6. Calcareous shale.

Under the first head we would put all clays and shales that contain at least fifty per cent. of kaolin and but little of anything else but finely divided silica. The fluxing elements are never more than five per cent., and usually much less, and oxide of iron is the one of these fluxing elements that occurs in much

*Ohio Geol. Survey, Vol. VII, Part I, p. 52.

the largest amount. The second division would include all of the ordinary clays and shales.

Beyer* in his report on the Iowa clays gives the following classification, which is based primarily on origin and secondarily on chemical and physical properties:

PRIMARY OR RESIDUAL CLAYS.

Entirely decomposed feldspathic rock.
Kaolin or China clay.
Partially decomposed feldspathic rock.
English Cornwall stone.
Porzellan Erde of the Germans.

SECONDARY OR TRANSPORTED CLAYS.

DEPOSITS IN STILL WATER.

Fire clays.
Highly refractory.
Flint fire clay.
Plastic fire clay.
Moderately refractory.
No. 2 fire clay.
Stoneware clay.
Sewerpipe clay.
Shales.
Slaty shales.
Bituminous shales.
Clay shales.

DEPOSITS FROM RUNNING WATER.

Alluvium.
Sandy clays.
Loam.

DEPOSITS FROM GLACIAL ACTION.

Leached—Whitish or red boulder clay.
Unleached—Blue boulder clay.

DEPOSITS BY WINDS.

Loess.

*Iowa Geo. Survey, Vol. XIV, p. 40.

In his report on the clays of West Virginia, Mr. G. P. Grimsley* makes the following classification of clays, based on origin and sub-divided according to their uses as determined by chemical and physical properties:

I. Residual Clays.

1. Kaolin.
2. China or porcelain clay.

II. Transported Clays.

(A) Refractory (fluxing impurities low)

3. Flint fire clay.
4. Plastic fire clay.

(B) Semi-refractory (fluxing impurities medium)

5. Paving brick clay and shale.
6. Sewer-pipe clay and shale.
7. Roofing tile clay and shale.
8. Stoneware clay.

(C) Non-refractory (fluxing impurities high)

9. Pottery clays.
   - (a) Ball clay.
   - (b) Flower-pot clay.
10. Brick and tile clay and shale.
    - (a) Ornamental brick clay and shale.
    - (b) Terra cotta clay and shale.
    - (c) Ornamental tile clay and shale.
    - (d) Common brick and tile clay and shale.
11. Gumbo ballast clay.
12. Slip clay.

Mr. H. A. Wheeler† has made the following classification of clay, based on the purposes for which each is to be used:

1. White ware.
   - Kaolin.
   - China clay.
   - Ball clay.

*West Virginia Geol. Survey, Vol. III, p. 70.
†Missouri Geol. Survey, Vol. XI, p. 25.

2. Refractory.
   - Plastic fire clay.
   - Flint clay.
   - Refractory shale.
3. Potters'.
   - Plastic clay and shale of moderate fusibility.
4. Vitrifying.
   - Paving brick clay and shale.
   - Sewer pipe clay and shale.
   - Roofing tile clay and shale.
5. Brick.
   - Common brick clay and shale.
   - Terra cotta clay and shale.
   - Drain tile clay and shale.
6. Gumbo.
   - Burnt ballast clay.
7. Slip.
   - Clays of very easy fusibility.

Mr. Geo. E. Ladd* makes the following classification of clays, considering them from a geological standpoint.

INDIGENOUS.

(A) Kaolins.
- (a) Superficial sheets.
- (b) Pockets.
- (c) Veins.

FOREIGN OR TRANSPORTED.

(A) Sedimentary.
- (a) Marine.
  1. Pelagic.
  2. Littoral.
- (b) Lacustrine.
- (c) Stream.
  1. Flood plain.
  2. Delta.

*Georgia Geol. Survey. Bull. No. 6a, p. 10.

(B) Meta-Sedimentary.
(C) Residual.
(D) Unassorted.

Mr. E. R. Buckley† makes the following classification of clays, which is a modification of the classification made by Ladd:

I. Residual Derived from
  (A) Granitic or gneissoid rocks.
  (B) Basic igneous rocks.
  (C) Limestone or dolomite.
  (D) Slate or shale.
  (E) Limestone.

II. Transported by
  (A) Gravity assisted by water.
    Deposits near the heads and along the slopes of ravines.
  (B) Ice.
    Deposits resulting mainly from melting of the ice of the Glacial Epoch.
  (C) Water.
    1. Marine.
    2. Lacustrine.
    3. Stream.
  (D) Wind.

One of the greatest troubles in trying to classify the clays is the fact that there is no sharp line separating them chemically, mineralogically, according to the way in which they have been formed, or according to their uses. Instead of this, however, they grade gradually from the best clays on the one hand to the poorest varities on the other.

Of the above classifications the one based on the uses to which the different clays are put is, perhaps, of as little value as any of them. This is due largely to the fact that there is such variation in the kind of clay used for any one purpose. Brick, for instance, are made from clays which vary much in composi-

†Wisconsin Geol. and Nat. Hist. Survey, Bull. VII, Part I, p. 14.

tion and which have been formed in entirely different ways. As an illustration of this we have in Western Washington around the Puget Sound country the glacial clay which is used in the manufacture of common brick, while in Eastern Washington in many places common brick are made from residual clays which have been formed by the decomposition of basalt. These clays are also very different in appearance and in composition. According to Wheeler's classification these would both, however, come under the same head. Buckley in his classification used a twofold basis, dividing all clays primarily as regards position and secondarily on their origin.

None of the classifications which have been made so far are entirely satisfactory in every particular. Some, however, will answer one purpose fairly well, while another will be used when the subject is considered from a different standpoint.

CHAPTER III.

GENERAL DESCRIPTION OF CLAYS.

In this report the clays will be described mainly in the order and under the headings given in the classification of Mr. G. P. Grimsley. Some of the different classes will be omitted, however, as they are not found in Washington. This plan is followed here mainly because it gives convenient divisions and headings under which to discuss the clays.

RESIDUAL CLAYS.

The residual clays are those that occur at the present time where they were originally formed. They are the result of the decomposition of the constituents of the original rocks of the earth's crust and contain less impurities as a general thing than those clays which have been transported for greater or lesser distances from their place of origin. The only impurities of any importance would be those derived from the rock from which the clay has been formed. As defined above, the residual clays are those formed only from the igneous rocks and would not include those formed from sandstones, limestones and other sedimentary rocks, even though they may occur in the place where these rocks have been decomposed.

The different minerals of which the various igneous rocks are composed when exposed to atmospheric agencies undergo certain changes or, as we say, weather, and through this weathering the clays are all formed, and hence are of secondary origin.

Kaolin.—The kaolins are those clays that in composition approach nearest to the mineral kaolinite and are the purest clays known. They are usually formed, when in anything like commercial quantity, from the decomposition of feldspars. They are white, or nearly so, in color, and are practically free from iron. They are of a rather light soft texture and usually have very little plasticity. Some kaolins have an appreciably plastic

feel, however. The tensile strength is low, the amount of water absorbed is large, as is also the amount of shrinkage.

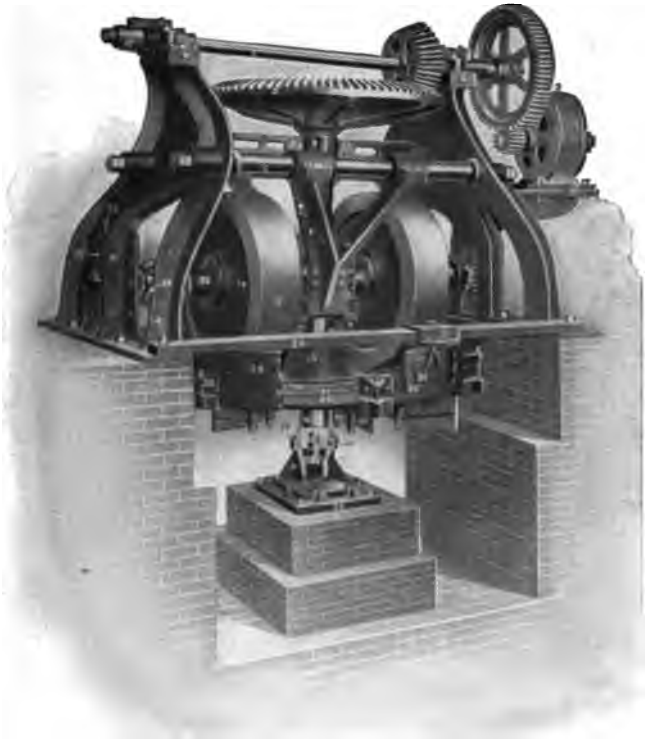
The kaolins usually have quartz, feldspar and mica present as grains disseminated through the mass, and as the relative amounts of these different minerals vary, the different properties of the kaolins will vary. The quartz and feldspar in a kaolin, unless in very fine grains, may be removed by washing. Under the microscope the kaolinite is shown to occur in bunches and isolated scales. Flakes and scales of white mica may also be recognized in this way. On account of their purity the kaolins are used for the manufacture of the better grades of ware, such as fine china or porcelain ware. They have so little plasticity, however, that they are not used by themselves, but are mixed with other more plastic clays. Finely ground silica is also added to counteract the shrinkage and feldspar to bind these all together when the mass is burned. All of these substances must be very finely divided so as not to give a rough surface to the ware after it has been burned. The hardness and density of the ware will depend largely on the temperature to which it is subjected in the burning.

The most famous china clays are those in France near Limoges and Sevres, and near Dresden in Germany. In the United States some very good china clays occur in North Carolina. The following table shows the chemical composition of a sample of the clay from each of these localities:

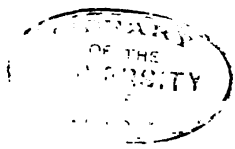
CONSTITUENTS	I.	II.	III.
Silica	45.70	56.39	56.15
Alumina	40.61	27.52	32.00
Ferric Oxide	1.39	0.36	0.64
Lime	0.45	1.52	0.35
Magnesia	0.09	0.41	Trace
Alkalies	2.82	4.29	0.47
Water	8.98	7.19	10.81
Moisture	0.35	.....	.....
	100.39	99.68	100.40

(1) Webster, N. C. Nor. Car. Geol. Survey, Bull. No. 13, p. 61.
(2) Limoges. U. S. Geol. Survey, 19th Ann., Pt. VI continued, p. 402.
(3) Dresden. U. S. Geol. Survey, 19th Ann., Pt. VI continued, p. 416.

So far as the writer is aware kaolins have not been found in commercial quantities up to the present time in Washington.



DRY PAN, THE STEVENSON COMPANY



These, however, as already stated, are formed by the decomposition of feldspars or from rocks containing a considerable amount of this mineral, such as granite, syenite, and rocks of this character. These rocks are very plentiful in certain parts of this state, and it is quite possible that kaolins might be found by carefully prospecting these localities.

TRANSPORTED CLAYS.

By far the larger part of the clays, as they occur at the present time, have been removed from the places where they first formed and deposited in others. These clays are formed, as are the residual clays, from the decomposition of feldspar or of rocks which contain feldspar. When this decomposition takes place on steep slopes the winds and rains remove the loosened material and it is washed down into the valleys and into the streams and carried by these sometimes for long distances before being deposited. By this means clays which differ in their properties may be washed together and mixed in one deposit.

The stream carries these fine clay particles in suspension so long as its velocity is maintained, but if for any reason this should decrease some of the clay material would be deposited, the coarsest coming first. If the stream empties into a still body of water, the clay will be spread out over the floor in more or less well marked strata or layers, and as these are added to from time to time, finally a well marked stratafication may be formed. Such deposits are spoken of as sedimentary clays. These different layers may vary much in thickness as well as in the physical condition of the material of which they are composed. These clays usually contain more impurities than the residual clays. They are more widely distributed, are much more common, and more important than the first class.

REFRACTORY CLAYS.

The refractory clays are those that have the property of resisting high temperatures and are therefore especially valuable for the manufacture of materials that are to be subjected to such

temperatures. Some of the more common products manufactured from these clays are fire-brick for furnaces, kilns, etc., crucibles, floor tiles, terra cotta, gas retorts, and glass pots. Refractoriness is the one essential property of all these clays and they vary within a wide range as regards their other properties such as plasticity, density, shrinkage, tensile strength, color and absorption. They also vary within certain limits as regards chemical composition. The amount, however, of the substances which act as fluxes such as the ferric oxide, lime, magnesia, and the alkalies, is small. For these refractory clays the amount of silica is also an important element. It has been found that silica at high temperatures acts as a flux so that of two clays with small amounts of the ordinary fluxing substances and which are alike in other respects except that one contains a larger amount of silica than the other, the one with the smaller amont of silica is the more refractory. Silica, then, as pointed out by Ries,* would be a high temperature flux, while iron oxide, lime, magnesia, and the alkalies would be low temperature fluxes.

The silica in these clays occurs either as free silica or combined with alumina and water to form an anhydrous aluminum silicate or kaolinite. The kaolinite is highly refractory and when heated will fuse at cone 35 or at a temperature of about 1,830 deg. C. In the kaolinite there is 46.3 per cent. of silica. The refractoriness of silica alone is almost as high as that of kaolinite but it has been found that in a mixture of these two in varying proportions within certain limits the fusion point will in every case be lower than that of either mineral separately. For the effect of high percentages of silica see kaolinite, chapter IV.

As already stated, these refractory clays may vary within a wide range as regards their physical properties. Some are plastic while others are practically devoid of plasticity, some are dense and compact while others are quite porous, some are very fine-grained while others are coarse-grained, some are almost

*Clays Occurrence, Properties and Uses, p. 170.

white while others may be very dark colored. Most refractory clays are high in shrinkage and some of the best grades show low tensile strength.

The refractory clays may be divided into the plastic and non-plastic clays. These non-plastic clays are hard and flint like, compact, and break with a conchodial fracture. On exposure to the air they may slake and crumble. They vary within wide limits as regards composition and color. In general on account of being non-plastic they can only be used when mixed with plastic clay.

The plastic fire clay may occur in connection with the flint or non-plastic clays. These differ from the flint clays in not being so compact in texture, do not break with conchodial fracture and will weather into a soft, sticky mass.

Many fire clays are found underneath coal beds. On this account it has been thought that these clays have been formed from ordinary clay by having the fiuxes such as alkalies, lime, etc., removed by the roots of the plants which grew in the swamps where these clays were deposited, or by the water of these swamps that, on account of the decaying vegetation present, would contain considerable amounts of organic acids which would dissolve these fluxes and in this way purify the clay.

In mixing the flint clays and plastic fire clays enough of the plastic clay is added to give a good bond so the brick may be handled without danger of breaking. The conditions which according to Orton,* produce a good fire brick mixture are as follows:

1. The power to resist high temperatures in the mixture comes mainly from the flint clay, hence there must be sufficient of this to give it this power.

2. The source of the physical strength of the brick when ready for use is the plastic bond. At very high temperatures when in actual use the flint clay softens and gives the brick its real strength.

*Geol. Survey of Ohio, Vol. VII, p. 223.

3. The loose, open porous texture is desirable to allow rapid absorption and radiation of heat and to allow rapid changes at high and low temperatures.

4. On account of the fact that the non-plastic clay has a very high shrinkage only those clays with a low shrinkage should be used for plastic bond. To obviate a part of this excessive shrinkage a part of the non-plastic clay should be calcined. A common mixture for this purpose consists of 45 per cent. of calcined flint clay, 45 per cent. raw flint clay and 10 per cent. of plastic bond.

A brick made from the above mixture should be used only when very high temperatures are to be reached so that some of the flint clay may become soft and plastic and the whole mass become slightly softened. Bricks made from the above mixture would have a loose porous texture and should not be used where they are subjected to medium or low temperatures or where they are subjected to friction of any kind.

The following table gives the composition of some of the best grades of refractory clays:

ANALYSES OF FIRECLAYS.

CONSTITUENTS	I.	II.	III.	IV.
Silica (SiO_2)	59.92	51.86	59.86	50.35
Alumina (Al_2O_3)	27.56	33.13	22.26	33.64
Ferric oxide (Fe_2O_3)	1.06	.78	3.06	.75
Lime (CaO)	Trace	Trace	.65	.....
Magnesia (MgO)	Trace	Trace	.42	Trace
Potash (K_2O)	.67	Trace	.63	.49
Soda (Na_2O)		Trace		.09
Sulphur trioxide (SO_3)	.....	.....	.35	.....
Titanic acid (TiO_2)	.....	1.91	1.01	.80
Water (H_2O)	9.70	12.50	10.20	11.75
Moisture	1.12	.....	2.74	2.13
Total	100.00	99.86	101.68	100.00

I. Salineville, Ohio, (flint clay). Ohio Geol. Survey, VII., p. 220.
II. Woodbridge, N. J. No. 1 fire clay. N. J. Geol. Survey, VI., p. 441.
III. St. Louis, Mo. Mo. Geol. Survey, XI., p. 571.
IV. Golden, Col. U. S. Geol. Survey, Mono. XXVII., p. 390.

The following table, compiled from over 200 analyses given in Bulletin, N. Y. State Museum No. 35, pp. 866-876, by H. Ries, shows the range and average composition of clays that are classed as fire clays:

COMPOSITION OF FIRECLAY.

CONSTITUENTS	Minimum	Maximum	Average
Silica (SiO_2)	34.40	96.79	57.909
Alumina (Al_2O_3)	0.85	46.61	28.094
Iron (Fe_2O_3)	0.01	7.24	1.506
Lime (CaO)	0.08	15.27	0.655
Magnesia (MgO)	0.08	6.25	0.512
Alkalies (K_2O, Na_2O)	0.048	5.27	1.460
Water (H_2O) loss on ignition	0.14	16.35	10.261
Total fluxes	.....	.....	4.184

SEMI-REFRACTORY CLAYS.

This group of clays is not used in the manufacture of ware that is to be subjected to very high temperatures. The ware made from these clays when burned should be dense and tough. The clays should vitrify at medium temperatures so that the particles may be brought closer together and the ware given a dense body and hence a small amount of pore space and low absorption. In the case of good fire brick as noted above porosity is desired while in the case of vitrified ware it is desired that the amount of porosity be small. The physical properties of these clays will vary within very wide limits. They are all plastic so that they may be readily molded into any shape desired. Clays which have the other properties needed for the manufacture of such vitrified ware as drain tile and paving brick may be so plastic that certain structures which are injurious may be developed in the ware by machinery. The clay should have good tensile strength so that the ware after it is dried may be handled and placed in the kilns without loss from breaking. It should have a low shrinkage and be capable of drying at a fairly rapid rate without warping and cracking.

While these clays must be fusible they should have the points of incipient fusion and viscosity so many degrees apart that the ware may be partly fused and still not melt the whole of the mass. This is one of the very important properties of a clay for this kind of ware. In burning it is very difficult to regulate exactly the temperature of the kiln. Then it is hard for the operator to know exactly when the proper amount of vitrification has been produced so that it is desirable to bring the temperature of the kiln up to the point that will produce incipient fusion and keep it there for a time so as to be sure of the proper amount of vitrification. If the points of incipient fusion and vitrification are only a few degrees apart it may not be possible to regulate the temperature of the kiln so as to do this without danger of melting the ware in the kiln. Then again the ware must have strength enough to support the weight of the ware which is above it and still retain its shape and to do this it must not be completely melted.

Paving Brick.—The material used for the manufacture of paving brick varies much and may range from surface clays, which are usually quite high in fluxing substances, to those that are low in these substances and hence semi-refractory. They are most frequently made from impure shales as these are often found to have the requirements for good paving brick. Shales which vitrify at medium temperatures are found in many places throughout the country. In many places clays and shales are mixed in order to get the desired result. The temperature at which incipient fusion takes place varies considerably in the different materials used for the manufacture of paving brick. The temperature of vitrification in the Ohio* paving brick material ranges from 1,712 deg. F. to 1,920 deg. F. The Iowa† clays range from cone .05 or about 1,922 deg. F. to cone 2 or about 2,138 deg. F.

The difference in temperature between the point of incipient fusion and vitrification in the best paving brick clays is from 300 deg. to 400 deg. F.

*Ohio Geol. Survey, Vol. VII, p. 138.
†Iowa Geol. Survey, Vol. XVI, p. 147.

The following analyses show the composition of some paving brick material:

ANALYSES OF PAVING BRICK MATERIAL.

CONSTITUENTS	I.	II.	III.	IV.
Silica (SiO_2)	57.45	51.07	65.00	56.62
Alumina (Al_2O_3)	21.06	25.78	19.30	21.63
Iron (Fe_2O_3)	7.54	6.83	4.91	7.08
Lime (CaO)	0.29	0.57	1.40	1.11
Magnesia (MgO)	1.22	1.26	0.40	1.41
Alkalies (K_2O and Na_2O)	3.66	3.44	2.60	3.62
Moisture (H_2O)	1.90	1.41	1.08	.....
Loss on ignition	5.90	8.70	5.51	6.53
Other constituents	.....	1.15	.....	.....
Totals	99.02	100.21	100.16	98.00

I. Columbus, Ohio. Ohio Geol. Survey, Vol. VII., p. 133.
II. Charleston, W. Va. W. Va. Geol. Survey, Vol. III., p. 230.
III. Moberly, Mo. Mo. Geol. Survey, Vol. XI., p. 413.
IV. Average of ten analyses of Ohio paving brick shales. Ohio Geol. Survey, Vol. VII., p. 133.

The following is given by Wheeler* as the range in composition of paving brick clays:

COMPOSITION OF VITRIFIED BRICK SHALE.

CONSTITUENTS	Minimum	Maximum	Average	Total Av.
Silica (SiO_2)	49.0	75.0	56.0	.....
Alumina (Al_2O_3)	11.0	25.0	22.5	.....
Ignition loss (H_2O, S, CO_2)	3.0	13.0	7.0	.....
Moisture (H_2O)	0.5	3.0	1.5	.....
Total non-fluxing constituents	.....	.....	.....	87.0
Iron (Fe_2O_3)	2.0	9.0	6.7	.....
Lime (CaO)	0.2	3.5	1.2	.....
Magnesia (MgO)	0.1	3.0	1.4	.....
Alkalies (K_2O, Na_2O)	1.0	5.5	3.7	.....
Total fluxing constituents	.....	.....	.....	13.0
Grand total	.....	.....	.....	100.0

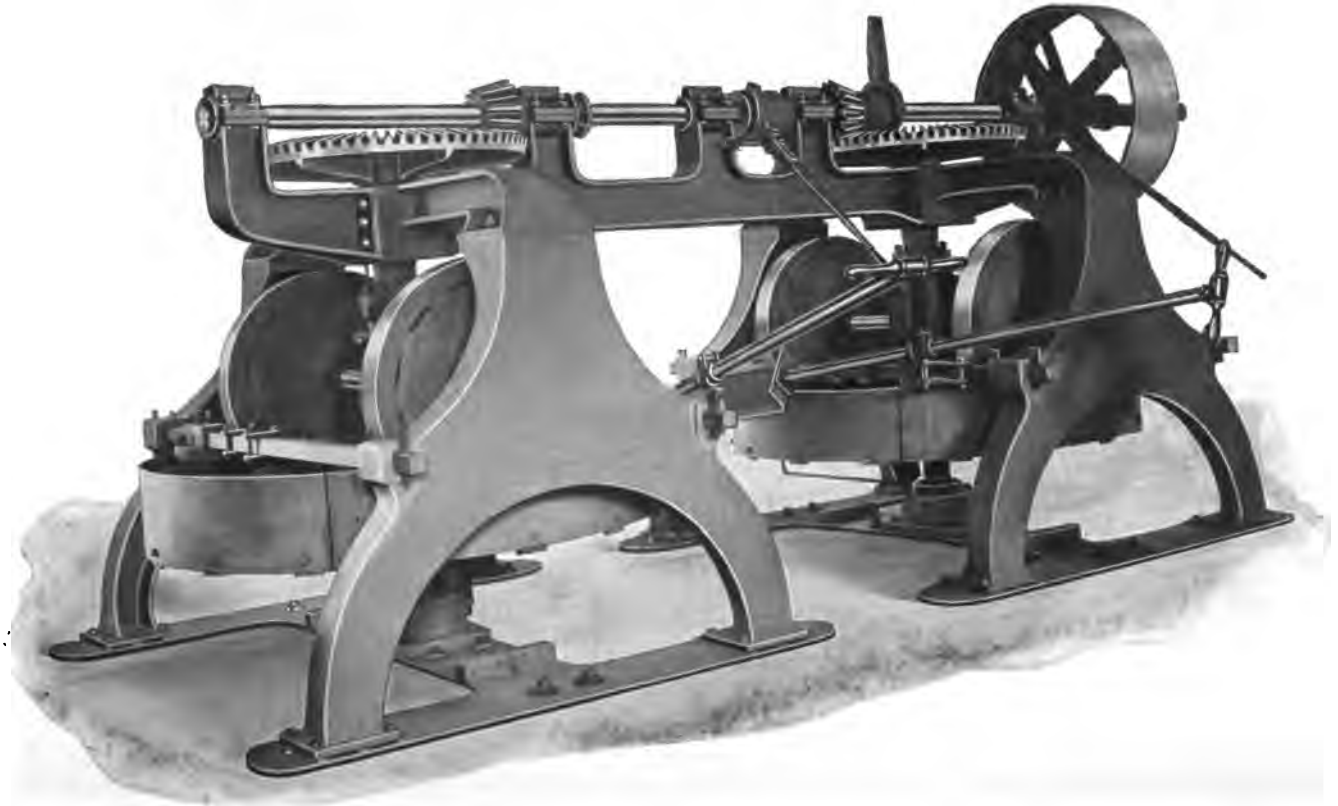
The above tables show the great range in the composition of the material that may be used in the manufacture of paving brick and still produce a very satisfactory product providing it has certain physical properties.

*Missouri Geol. Survey, Vol. XI, p. 456.

It should be plastic enough so that it may be worked in an auger machine and worked as cheaply as possible. Too great plasticity, however, may produce lamination. Often to get the best results as regards plasticity two or more clays are mixed in certain proportions. The amount of shrinkage in air drying or in burning should not be extremely large as it would be apt to produce cracking and warping of the ware. The rate at which the brick may be dried without injury is of considerable importance and the longer it takes, the more expensive it will be to make the brick. Density is a factor in determining the durability of the brick and hence it is desirable that the clay should be of such character as to produce dense brick, as, other things being equal, these will be the most durable. It should burn to a very tough, strong body as this is one of the essentials of a good paving brick. The clay should also have good tensile strength.

Sewer Pipe.—The clays from which sewer pipe may be made are very similar to those for the manufacture of paving brick. The sewer pipe have to be vitrified in burning and hence for their manufacture a clay high in fluxes is needed. The clay must be plastic enough so that it can be easily molded and should burn to a dense smooth body. The shrinkage both in drying and burning must be low so that there will be the least danger of loss from cracking and warping. The dark colored sewer pipe seems to meet with the most ready sale and hence a clay should have iron enough to give this color to the burned ware. A high iron percentage is also said to aid in the formation of the salt glaze* which is usually given to sewer pipe. The silica is also of importance in producing this glaze and hence clays with free silica are desirable. Impure fire clays are often used for sewer pipe, as are also mixtures of fire clay and shale or clay. The fire clays usually make a light colored pipe which does not sell as readily as the dark colored ones, and on this account some clay which contains a considerable amount of iron is usually mixed with the fire clay.

*Ries, Clays, Occurrence, Properties and Uses, p. 183.



DUPLEX WET PAN, THE AMERICAN CLAY MACHINERY COMPANY

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The following analyses show the composition of the clays that are used for the manufacture of sewer pipe in several different localities:

ANALYSES OF SEWER PIPE CLAY.

CONSTITUENTS	I.	II.	III.	IV.	V.
Silica (SiO_2)	58.38	59.96	68.00	57.52	59.70
Alumina (Al_2O_3)	20.89	15.76	23.57	21.76	27.00
Ferric oxide (Fe_2O_3)	5.78	7.72	1.87	3.41	2.10
Ferrous oxide (FeO)	.....	.....	.46	3.70	.....
Magnesia (MgO)	1.57	.93	.89	.88	.82
Lime (CaO)	.44	.60	.44	.60	.60
Potash (K_2O)	4.68	3.66	2.40	3.57	1.96
Soda (Na_2O)	.34	.....	.29	.08	
Loss in ignition	.....	.....	.....	7.27	8.20
Phosphorus pentoxide (P_2O_5)	.....	.....	.....	.14	.....
Titanium oxide (TiO_2)	.....	.....	1.10	.83	.....
Water (H_2O)	7.53	7.70	6.45	.86	.....
Sulphur trioxide (SO_3)	.....	.73	.....	.....	.....
Totals	99.61	97.06	98.88	100.57	100.06

I. Columbus, Ohio. Ohio Geol. Survey, Vol. VII, p. 133.
II. St. Louis, Mo. Mo. Geol. Survey, Vol. XI. p. 570.
III. Mecca, Ind. Indiana Geol. and Nat. Res. 29th Ann. Rept., p. 219.
IV. New Cumberland, W. Va. W. Va. Geol. Survey, Vol. III, p. 219.
V. Baltimore, Md. Md. Geol. Survey, Vol. IV, p. 431.

Roofing Tile.—Clays for the manufacture of roofing tile in general should fuse at low temperatures and produce a vitrified product. The tile when burned, should have a dense, tough body so it will not absorb a large amount of water and so as not to break in handling. It should have a low air and fire shrinkage so as not to crack or warp in drying and burning. The clay must have good plasticity and bonding power. It should contain iron enough to give the red color which is usually desired. In some localities the roofing tiles are not vitrified in burning. These are satisfactory for use in a mild climate but in the greater part of the United States the tile should be vitrified. In the western part of Washington there is so little cold weather during the winters that the softer tiles should prove satisfactory and eventually be used to a considerable extent. Tiles are more durable than shingles, they are fire proof, make a roof that is cool in summer and warm in winter, and they are permanent in color. If hard burned they resist the climatic changes of any locality.

Stoneware.—The clays used for this kind of ware vary within a given range as regards some of their properties. The most important of these and the one that is the most constant is that of plasticity. To be a good stoneware clay it must be highly plastic. This is necessary in order that it may be molded and formed into the various shapes desired and it must retain these until the clay is dried and burned.

Wheeler* gives the following as the properties required in a stoneware clay:

"(1) Eminently plastic, (2) free from coarse sand or other coarse foreign matter, (3) as free from iron as possible, (4) capable of burning to a close, incipiently vitrified body at a temperature less than 2,200 deg. F., (5) should have a range of at least 200 deg. between the point of incipient and complete vitrification, (6) capable of drying and heating at moderate speed without the employment of grog, (7) tough and strong body when burned, (8) free from carbonates, sulphates or other salts that are liable to cause blisters in burning."

The effect of coarse sand in a stoneware clay would be to produce spots and blemishes on the surface of the ware. As most clays contain more or less coarse particles it becomes necessary to wash them before they are used and in this way remove these substances. The clay should not contain any large amount of iron mainly on account of the fact that the light colored wares sell more readily. The iron would give to the body of the ware a dark color. The ware should at any rate have a uniform color, and in order to insure this the iron should be very finely divided and evenly disseminated through the clay. If the iron occurs in the form of sulphide or pyrite it must be removed or else it will make spots in the ware which will injure its sale.

The clays must be those that will vitrify at comparatively low temperatures; however, they must be refractory enough so the ware will stand up well and hold its shape at temperatures sufficient to melt the glaze. This is very necessary as the slip, in the case of either an artificial or a clay slip, must be melted and if

*Missouri Geol. Survey, Vol. XI, pp. 299-300.

the temperature which melts the slip melts the ware also, of course the clay would be of no value. The higher the temperature necessary to produce incipient vitrification the more fuel needed in the burning and hence the more expensive to manufacture the ware. The ware should be completely vitrified to give it density, hardness, and strength. It should not, however, be burned so as to make it glassy or brittle.

There should be a difference of from 200 deg. F. to 400 deg. F. in temperature between the point of incipient vitrification and complete vitrification. This is necessary on account of the fact that it is not possible to regulate within less than about 200 deg. F. the temperature of the burning kiln, and in order to be sure to completely vitrify the ware and still not completely melt it, the operator should have this much margin.

For several reasons the clay should have the properties that will allow of rapid drying and burning. Ware can be more cheaply manufactured from such clays than from those that must be dried slowly because there is less loss from breaking while the ware is still soft; then it will require less space for drying to handle the output of the plant. On account of the thinness and smoothness required in the ware it is not possible to produce these conditions by the addition of grog without injury to the ware. The various uses to which stoneware is put require that it be strong and able to withstand rough usage, hence the clay must burn to a strong, tough body.

The presence of carbonates, sulphates, and other substances which in the burning of the clay will give off gases is injurious as they will tend to form blisters in the ware and make it unsalable.

It is also desirable that the clay should have a tensile strength of at least 125 pounds to the square inch.* It should also have a low air and fire shrinkage.

The following analyses show the composition of clays that are

*Ries, Clays, Occurrence, Properties and Uses, p. 180.

being used in a number of different localities in the manufacture of stoneware

ANALYSES OF STONEWARE CLAY.

CONSTITUENTS	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	64.26	71.94	67.84	73.33	69.23	61.64
Alumina (Al_2O_3)	22.95	17.60	21.83	14.98	18.97	24.20
Ferric oxide (Fe_2O_3)	1.28	2.35	1.57	1.75	1.57	2.10
Ferrous oxide (FeO)	.....	.....	.....	.24	.55	.....
Lime (CaO)	.45	.62	.28	.43	.12	.30
Magnesia (MgO)	.37	.56	.24	.45	.36	.78
Potash (K_2O)	1.96	1.50	2.24	1.96	2.27	2.38
Soda (Na_2O)	.....	.....	.....	.29	.33	.16
Titanic acid (TiO_2)	.....	.....	.....	.81	1.50	.50
Water (H_2O)	6.74	5.27	5.90	1.32	5.46	.....
Moisture	2.05	1.01	.80	.....	.....	1.18
Loss on ignition	.....	.....	.....	4.46	.....	6.66
Totals	100.06	100.85	100.70	100.14	100.36	100.14

I. Zanesville, O. Ohio Geol. Survey, Vol. VII, p. 74.
II. Calhoun, Mo. Mo. Geol. Survey, Vol. XI, p. 564.
III. Woodbridge, N. J. N. J. Clay Report 1878, p. 99.
IV. Parkersburg, W. Va. W. Va. Geol. Survey, Vol. III, p. 159.
V. Huntingburg, Ind. Ind. Geol. and Nat. Res. 29th Ann. Rpt., p. 508.
VI. Clayton, Washington. W. B. Bloor, analyst.

The following table compiled from chemical analyses given in Bulletin New York State Museum, No. 35, pp. 878-881, by Ries, shows the range in, and average composition of clays that are being used in the manufacture of stoneware:

COMPOSITION OF STONEWARE CLAYS.

CONSTITUENTS	Minimum	Maximum	Average
Silica (SiO_2)	44.14	86.98	61.939
Alumina (Al_2O_3)	12.99	39.80	21.311
Iron (Fe_2O_3)	0.16	15.75	2.914
Lime (CaO)	0.011	9.90	1.096
Magnesia (MgO)	0.05	4.80	0.85
Alkalies (K_2O and Na_2O)	0.52	7.11	2.06
Water (H_2O) loss on ignition	1.32	20.00	8.561
Total fluxes	.....	.....	6.922

NON-REFRACTORY CLAYS.

The clays treated under this division have a very wide range as regards appearance, composition and physical properties. The division includes those clays which are used in the manufacture of the larger part of the common structural materials and also the common pottery clays.

Ball Clay.—The ball clays are such as have a high degree of plasticity, are white when burned, and are of sedimentary origin. On account of their high plasticity they are used as a bond with the non-plastic kaolins in the manufacture of white ware. They should be free, or practically so, from iron, and should be tough and waxy. They should have a fair tensile strength. The number of different places in the United States where ball clays are known to occur is not large. The most important localities are Edgar, Florida; Woodbridge, N. J.; and Mayfield, Ky. These ball clays vary within quite wide limits as regards fusibility, some vitrifying at low temperatures. Refractoriness, however, is to be desired. In some cases these clays are washed before they are used.

Flower-Pot Clays.—The clays used for the manufacture of flower pots are usually of the poorer qualities. They may contain a considerable amount of iron in which case the flower pots will be red in color. Potters' clays are sometimes used when light colored pots are desired. They are burned at low temperatures and the ware has an open porous structure. It is sometimes glazed on the outside to give it a better appearance. The pots are molded either by hand, in plaster of Paris molds, or in a press. The clays should have good plasticity and fair tensile strength.

The building brick and tile clays are usually what are considered the poorer grades of clays. They may contain a high per cent. of fluxes, and are often quite sandy. The clays from which these materials are manufactured, while of a low grade, form the most important group of clays on account of the very large amount of material manufactured from them. They are widely distributed geographically, there being but few localities that do not have clay from which a fair grade at least of common brick may be manufactured. They are not as a general thing suited to the manufacture of vitrified wares, as they contain a large amount of fluxing materials and hence would fuse at low temperatures and rapidly and destroy the shape of the ware.

Ornamental Brick.—The various shapes and sizes of brick that are used mainly for ornamental purposes are classified under this head. They are made by the dry press method or by the semi-dry process. The number of shapes and forms of these is practically unlimited. These brick in general call for a higher grade of clay than do the ordinary brick. The clays in use at the present time vary within a considerable range, but the most common ones are those that give, when burned, a red, a white, or a buff product and are fused at medium temperatures. The physical requirements of a clay for this kind of ware as given by Reis* are, (1) uniformity of color in burning, (2) freedom from warping and splitting, (3) absence of soluble matter, and (4) sufficient hardness and low absorption when burned at a moderate temperature.

Clays that are to be used for ornamental purposes should not contain any very large amount of coarse sand. These clays will vary within a considerable range as regards shrinkage and tensile strength. The desired color may be obtained from a single clay, from a mixture of clays or by the addition of artificial coloring agents.

Terra Cotta.—The clays used for the manufacture of terra cotta are of many kinds. These clays should give uniform colors, strong body, and burn without checking, cracking or warping. Manufacturers at the present time are using very largely semi-refractory clays or mixtures of these with clays that are less pure and fuse at lower temperatures. Formerly the color that these clays would give when burned was an important point, but at present the desired color is obtained very largely by means of slips applied to the terra cotta before it is burned. These slips may give to the surface of the ware a dull, an enameled, or a glazed surface according to the composition of the material used for the slip.

It is very necessary that clay for terra cotta should dry and burn without warping, and as every piece has to have an exact size when burned so as to fit exactly into its place in the build-

*Clays, Occurrence, Properties and Uses, p. 187.

ing, or whatever it may be, it becomes absolutely necessary that the operator should know exactly how much his clay will shrink in drying and burning that he may know how large to mold his ware in order to get this result. The drying of the ware has to be done very carefully, the larger pieces often being protected by a damp cloth so as to prevent too rapid drying and cracking.

The following table is given to show the wide range in composition of the material being used in the manufacture of this kind of ware:

ANALYSES OF TERRA COTTA CLAYS.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	68.30	63.11	44.20
Alumina (Al_2O_3)	21.27	23.11	38.66
Iron (Fe_2O_3)	1.43	1.79	0.74
Lime (CaO)	0.52	0.42	.....
Magnesia (MgO)	0.80	0.70	.....
Alkalies (K_2O and Na_2O)	0.20	3.71	0.46
Titanium (TiO_2)	.....	.....	1.20
Water (H_2O)	7.55	7.05	14.55
Totals	100.07	99.89	99.81
Total fluxes	2.95	6.62	2.40

I. Arundel clay, Baltimore Co., Md. Md. Geol. Survey, Vol. IV, p. 435.
II. Shale, Billings, Mo. Mo. Geol. Survey, Vol. XI, p. 452.
III. Fire clay, Sayersville, N. J. New Jersey Geol. Survey, Final Report, Vol. IV, p. 521.

Terra cotta clays should contain but small amounts of soluble salts of any kind. This is desirable on account of the fact that in the drying of the wares they may come to the surface, and when it is burned would effect the color. They should be clays that have a good degree of plasticity so that they may be readily worked into the various parts of the molds. They should burn to a dense hard body at medium temperatures.

A sample of clay from Staten Island, New York, which is used for terra cotta had the following properties according to Ries:*

"It possesses the advantage of being very plastic, burning to a deep red, with a very dense body at a comparatively low temperature. It took 33.70 per cent. of water to work it up. The air shrinkage was 6 per cent., and at cone .06, it was 9.5 per cent. Incipient vitrification began at .03, with 12 per cent.

*New York State Museum, Bull. No. 35, p. 760.

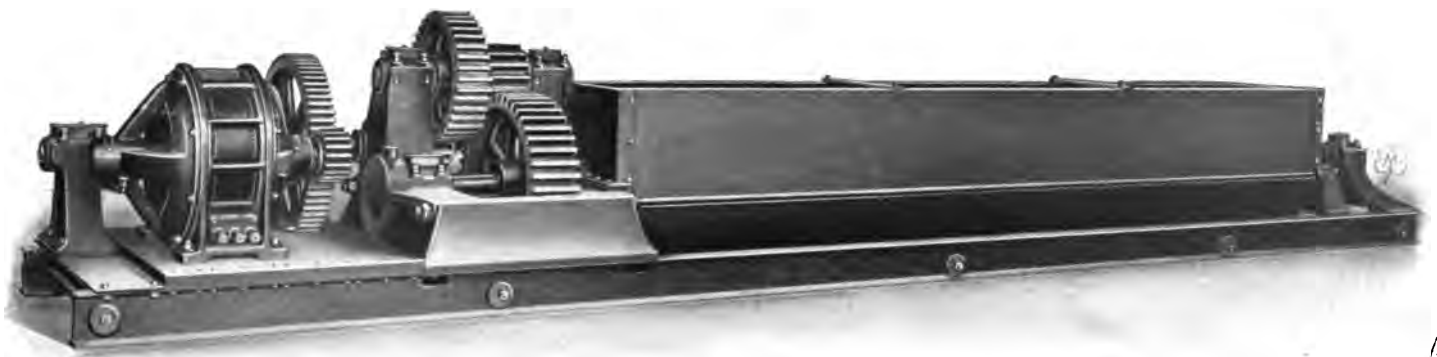
shrinkage; complete vitrification was reached at 4. Viscosity at 6. The percentage of soluble salts contained in the clay was .25 per cent. The tensile strength showed a minimum of 75 pounds and a maximum of 90 pounds to the square inch. The clay slakes quite rapidly in water."

Buff burning clays are being used perhaps more than almost any other kind at present for the manufacture of terra cotta.

Common Brick and Tile.—The clays or shales used for the manufacture of common building brick vary within a wide range as to composition and physical properties. They are usually low grade, more or less impure sandy clays. They usually burn to a red color on account of containing a considerable amount of iron. They should burn to a dense, hard body at low temperatures. On account of the fluxing material present they usually fuse rapidly at high temperatures and hence would not be suited to the production of vitrified wares. These clays should mold easily and should dry and burn without cracking and without an excessive amount of shrinkage. Many clays have a larger amount of air and fire shrinkage than is desired and this is often overcome by the addition of a sandy clay. In the manufacture of common brick the chemical composition, only within very wide limits, is not of very great importance. The physical properties, however, may determine to a considerable extent the methods to be adopted in the manufacture of the brick.

The iron present gives the color to the red brick and when lime and magnesia are present in considerable amounts, the clays burn to cream and buff colors. The fluxing impurities usually range from about 8 to 14 per cent. The best results are usually obtained with clays which contain from 5 to 7 per cent. of ferric oxide.* The clay should reach the condition of incipient vitrification at a moderate temperature, 2,000 deg. F. being given as the extreme, and should fuse to a dense, hard body at this or a lower temperature. The red burning clays are used to a much greater extent in the manufacture of common brick than any others partly because they are more common

*Ries, Professional Paper, U. S. Geol. Survey, No. 11, p. 45.



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and then again they are more apt to burn to a dense body at a low temperature.

The clays suitable for the manufacture of common brick are widely distributed throughout the country, there being hardly a locality in which they are not present. In some places very low grade clays are used.

The following figures give the maximum, minimum and average percentage of the different constituents in brick clays, the results having been obtained from a number of analyses of clays from different parts of the country:*

ANALYSES OF BRICK CLAYS.

CONSTITUENTS	Minimum	Maximum	Average
Silica (SiO_2)	34.35	90.877	59.27
Alumina (Al_2O_3)	2.14	44.00	22.774
Ferric Oxide (Fe_2O_3)	.126	22.12	5.311
Lime (CaO)	.024	15.33	1.513
Magnesia (MgO)	.02	7.29	1.052
Alkalies (K_2O and Na_2O)	.17	15.32	2.768
Water (H_2O)	.05	13.60	5.749
Moisture	.17	9.64	2.505

The clays used for drain tile are similar to those that are used for common brick and vary widely in composition and physical properties. Many shales are also well adapted for the manufacture of drain tile. As in the case of common brick almost any plastic clay that can be dried without cracking, burned to a porous body, and has a fair degree of strength will answer for drain tile. The requirements for a drain tile are that they should have a soft, porous body that has not been vitrified in burning. It should also have a good degree of strength. The ware must be porous enough for the water to penetrate it readily. The color is of no real value but the light red is the most common one. Clays that are very plastic are apt to check in drying and burning and those that are very sandy will make a weak tile, so that neither of these conditions are desirable where the clay is to be used alone.

*Ries, Bull. New York State Museum, No. 35, pp. 525, 639, 882 to 898. Geol. Survey of New Jersey, Vol. VI, pp. 55, 64 and 67.

GUMBO CLAY.

In a number of places, especially in certain of the Mississippi Valley states, a fine-grained, very plastic tough clay is found which, when burned, is used to a considerable extent as railroad ballast. These clays have a high air and fire shrinkage. When subjected to heat they break up into small particles which make them valuable as ballast. The clay contains a high percentage of fluxing substances and hence can be burned at low temperatures. These gumbo clays are usually black in color on account of having considerable organic matter present.

They do not differ chemically from the clays that are used for common brick, drain tile, sewer pipe, or paving brick, and their "peculiar value for burnt ballast is entirely a physical one."*

SLIP CLAY.

Slip clays are those that have a large amount of impurities which act as fluxes and cause the clays to fuse at low temperatures. A good slip clay should be fine grained, of uniform texture, and have a low air shrinkage. They should give a uniform color when fused and should not crack or check. In burning, the slip forms a natural glaze on the ware. There are several localities in the United States where slip clays occur, but none of the clays, with the exception of the Albany slip, have been entirely satisfactory when used alone. The natural clay slips, when good, are more satisfactory than artificial slips.

"A good slip clay makes a glaze which is free from the defects common to artificial glazes. It will fit a wide range of clays and since it is a natural clay will undergo the same changes in burning as the body on which it is placed. Artificial mixtures of exactly similar composition to the natural clays have failed to give the excellent results as to gloss or color, that are obtained by the natural clay."†

The slip is applied to the ware by being first mixed with water so that it forms a very thin paste and then is either sprayed over the ware or the ware is dipped into the slip.

*Wheeler, Mo. Geol. Survey, Vol. XI, p. 543.
†Beyer and Williams, Iowa Geol. Survey, Vol. XIV, p. 224.

The following are given as the properties of a slip clay:*

"Physically it must be exceedingly fine-grained and free from concretionary matter; the proportion of lime and magnesia must be high, ranging from 6 to 12 per cent.; the iron content should be sufficient to produce a good brown color, 5 to 7 per cent.; that the clay be fusible it must be high in alkaline minerals; the clay must have a low shrinkage in drying and must mature in burning as little above 2,250 deg. F. as possible."

The following analyses show the composition of some slip clays from different parts of the United States:

ANALYSIS OF SLIP CLAYS.

CONSTITUENTS	I.	II.	III.	IV.	V.
Silica (SiO_2)	55.60	43.94	63.63	58.50	52.94
Alumina (Al_2O_3)	14.80	11.17	13.57	13.89	23.13
Ferric oxide (Fe_2O_3)	5.80	3.81	7.77	3.29	6.72
Lime (CaO)	5.70	11.64	2.55	2.34	2.99
Magnesia (MgO)	2.43	4.17	1.47	1.61	3.21
Potash (K_2O)	3.23	2.90	2.63	7.63	4.62
Soda (Na_2O)	1.07	.71	.38		
Manganese oxide (MnO)	.14	.....	.....	.....	.....
Phosphorus pentoxide (P_2O_5)	.15	.....	.....	.....	.....
Water (H_2O)	5.13	3.90	4.75	6.70	1.56
Carbon dioxide (CO_2) and moisture	4.94	15.66	2.90	3.70	.....
Total	98.09	98.00	100.15	100.46	99.90

I. Albany, New York. Ohio Geol. Survey, Vol. VII, p. 105.
II. Rowley, Mich. Ohio Geol. Survey, Vol. VII, p. 105.
III. Brimfield, O. Ohio Geol. Survey, Vol. VII, p. 105.
IV. Piedmont Springs, Tex. Texas Geol. Survey, 4th Ann. Rept.
V. Boesburg, Wash. W. R. Bloor, Anal.

*Beyer and Williams, Iowa Geol. Survey, Vol. XIV, p. 225.

CHAPTER IV.

CHEMICAL PROPERTIES OF CLAY.

Many different elements occur in the various rocks that are found in the earth's crust. Only a few of these, however, are very common and important in a study of the clays. These different elements are not found, with a few exceptions, occurring as elements but as chemical combinations of these and it is these combinations that produce what we know as minerals. For instance oxygen an element and silicon another element unite to form silica, (SiO_2) one of the very common mineral substances occurring in nature. These different elements when they unite also unite in certain definite proportions. In the example given above one atom of silicon unites with two of oxygen and in quartz they never unite in any other ratio so that minerals are substances having a definite composition.

The number of different minerals known at the present time is very large but by far the larger part of any clay is composed of only a few minerals, comparatively, the most important of which will be considered in this chapter.

KAOLINITE.

Kaolinite is the material that by many is considered as forming the base of all clays. It is a hydrous silicate of alumina (Al_2O_3, $2SiO_2$, $2H_2O$) and contains 46.3 per cent. of silica, 39.8 per cent of alumina, 13.9 per cent. of water. This is a soft mineral, white in color and has a specific gravity of about 2.5. When wet kaolin becomes plastic and it may be worked into various shapes and forms. Its plasticity, however, is low and its tensile strength is weak.

Kaolin is a secondary mineral formed from the decomposition of other minerals, usually from the feldspars. It is not easily decomposed and but little effected by the atmospheric agencies. It fuses only at very high temperatures. When

heated to a high enough temperature it is dehydrated leaving Al_2O_3, $2SiO_2$ which fuses at 3,326 deg. F. or 1,830 deg. C. Alumina alone requires even a higher temperature than this to melt it but the silica which melts at a lower temperature than the alumina acts on it as a flux. The effect of silica, in different amounts, on alumina as given by Beyer* is as follows:

"Mixtures of these two oxides vary in fusibility with the proportions of each present. Additions of silica to alumina lower the fusion point until a mixture with the molecular proportions Al_2O_3, $17SiO_2$, has been reached. This is the most fusible admixture of the two substances. Up to this point silica acts as a flux. Further increment in the silica content causes the resulting mixture to become less fusible. For instance, Al_2O_3, $20SiO_2$ would stand a higher temperature before fusion than Al_2O_3, $18SiO_2$. The influence of the silica has reached its maximum, beyond which point it continues to approach the true melting point of free silica, which, however, is not so high as that of alumina."

Other hydrated silicates of alumina, sometimes occur associated with the kaolinite. These may be either cystallized or amorphous in form and are thought by some to be different species of kaolinite.

QUARTZ.

Quartz is always present in greater or lesser amounts in all clays. The amount, however, in some cases, as in some of the best kaolins of New Jersey, is small, being in this case only two-tenths of one per cent.† It occurs usually in very small grains, in most cases being so small that it cannot be seen with the naked eye. The shape of these grains will vary much and in general will be more irregular in outline and sharp cornered in the residual clays than in the transported or sedimentary ones. This, of course, is due to the greater amount of grinding together of these particles while being transported by the stream or while being dashed about by the wind or the waves before they were finally deposited in deep water. These quartz grains may be either transparent or translucent and colorless or they

*Iowa Geol. Survey, Vol. XIV, p. 54.
†Cook, Geol. Survey, N. J., Report on Clays, p. 273.

may be colored, usually, however, simply on the surface, red or yellow by iron oxide. Quartz is a very hard mineral, has no cleavage, brakes with a conchoidal fracture and resists well the action of atmospheric agencies.

In addition to occurring in the free state as quartz, silica also occurs in the clays in the combined state to form the different silicate minerals that are found in the clays. In ordinary chemical analyses the total silica is usually given and includes both the free and the combined. The common silicate minerals found in the clays are kaolinite, feldspar, mica and hornblende. These silicate minerals with the exception of the kaolinite all have a tendency to occur in a more or less sandy condition and hence in their effect on shrinkage and plasticity would be the same as that of quartz.

The following table taken from Ries'* report on the clays of New York shows the variation of total silica in several different classes of clays, the results having been obtained from several hundred analyses:

AMOUNT OF SILICA IN CLAYS.

KIND OF CLAY	Per Cent. of Total Silica		
	Minimum	Maximum	Average
Brick Clays	34.35	90.877	59.27
Pottery Clays	45.06	86.98	45.88
Fire Clays	34.40	96.79	54.804
Kaolins	32.44	81.18	55.44

As shown by the above table the amount of total silica found in clays varies between wide limits. This is due to a variation of both quartz and the combined silica. Theoretically kaolinite should have 46.4 per cent. of silica and as shown by the above table it usually has more, the average being 55.44 per cent. In a few cases it has been found to be even less than the theoretical amount.

Sand exerts a very marked effect on the plasticity and shrinkage of clays. The result is that the amount of shrinkage and the plasticity and tensile strength all decrease on the addition of

*Bull, N. Y. State Museum, No. 35, p. 525.

sand to any clay. The result will be the same whether the sand be composed of quartz alone or whether it is made up of particles of silicate minerals. The amount of shrinkage will also vary with the size of the grains, being greatest where the material is coarsest. It has been shown that the addition of sand causes a decrease in plasticity in direct proportion as the size of the sand grains increase. Professor Edward Orton* after a large number of experiments established the following law in regard to this question: "That the non-plastic ingredients of a clay influence its tensile strength inversely as the diameter of their grains, and fine-grained clays will, other things being equal, possess the greatest tensile strength." Quartz also tends to prevent warping and cracking of the ware, which is so liable to take place in the material molded from the very plastic fat clays. The fact that quartz fuses only at very high temperatures and expands slightly on heating accounts for its effect in decreasing shrinkage. This expansion of the quartz to a certain extent overcomes the shrinkage of the other minerals. In some cases where the per cent. of quartz is very large and the individual grains are also large, Reis† says, it has even been known to cause expansion during burning.

Quartz also exerts a chemical influence as well as a physical one, on a clay. Being a substance that by itself is fused only at very high temperatures, it would at low and medium temperatures act as a refractory agent and would tend to hinder the fusion of the clay. At very high temperatures and especially in the presence of other substances usually found in clays in greater or lesser amounts quartz acts as a flux and tends to reduce the refractoriness of the material and for this reason a high per cent. of silica for a very refractory clay is not desirable.

FELDSPAR.

Feldspar is often found associated with quartz in clays and is not easily distinguished from the quartz. This is a mineral, however, with a somewhat complex composition. All feldspar

*Trans. Am. Ceram Society, Vol. II, p. 100, and Vol. III, p. 198.
†Geol. Survey of Mich., Vol. VIII, p. 11.

contains alumina and silica with more or less potash, soda or lime. There are several different species of these feldspars and on account of variation in composition and physical properties they are known by different names some of the more common ones being given below with their theoretical compositions:

COMPOSITION OF FELDSPARS.

FELDSPAR SPECIES	CHEMICAL COMPOSITION				
	Silica	Alumina	Potash	Soda	Lime
Orthoclase	64.70	18.40	16.90	.....	.....
Albite	68.00	20.00	.....	12.00	.....
Oligoclase	62.00	24.00	.....	9.00	5.00
Labradorite	53.00	30.00	.....	4.00	13.00
Anorthite	43.00	37.00	.....	.....	20.00

Feldspars occur in various sized grains which are usually colorless, red, pink, or white. When fresh and undecomposed they have a bright lustre and well marked cleavage planes along which they split quite readily. The feldspars are softer than quartz and are much more readily attacked by the atmospheric agencies and when decomposed the product is a kaolinite. According to Wheeler* all clays and shales contain feldspar, the amount varying from as low as less than one per cent. in some clays, to as much as 25 per cent. in others. The feldspar grains which occur in the clay act in the same way that quartz grains do until the point of fusion of the feldspars is reached, that is, they will tend to decrease the amount of air shrinkage, plasticity, and tensile strength. The temperature at which the different species of feldspars fuse is different, so that the temperature to which any clay can be subjected without fusing these grains of feldspar will depend on the kind of feldspar present in the clay.

The feldspars are the principal sources of the very strong fluxing elements, potash and soda, found in clays. The most common feldspar is orthoclase, and this is the one also that has the highest fusing point, melting at about 2,250 deg. F., so that until this temperature is reached it would not act as a flux but after this, however, it would act as a very strong flux. Oligo-

*Missouri Geol. Survey, Vol. XI, p. 60.

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clase fuses at a temperature of about 1,733 deg. F. Orthoclase as shown in the above table is a potash feldspar while oligoclase is a soda lime feldspar. According to Wheeler* soda is a stronger flux than potash. Soda again is found in the feldspars that melt at the lowest temperatures, so that it is readily seen that the kind of feldspar found in any particular clay will have much to do with the temperature at which the clay will fuse.

MICA.

Mica is found in greater or lesser amounts in nearly all clay and as a general thing is easily recognized with the naked eye on account of the fact that it usually occurs in thin scales with bright shining surfaces. Mica is a complex silicate in which alumina is the essential base with potash, iron oxide and magnesia as the other common substances which act as bases. While there are a number of different species of this mineral muscovite and biotite are the ones that are found most frequently in the clays. The muscovite is a silicate of alumina with potash. It is usually white in color and, like all micas, is capable of being split into very thin layers. It resists the action of the atmospheric agencies better than the feldspars and also better than the biotite and for this reason is found much more frequently in the clays than the biotite. The black mica or biotite is a silicate of alumina, iron, and magnesia, and on account of the iron that it contains decomposes more rapidly than the muscovite. According to Reis† mica lowers the plasticity and tensile strength of clays, the effect on the latter becoming very marked as the amount of mica increases. According to this same authority‡ muscovite or "white mica tends to increase the refractiveness of a clay, and to exert very little fluxing action, even at moderately high temperature."

IRON

Iron is a very common constituent of almost all clays, and occurs in a number of different forms. It is the principal cause

*Missouri Geol. Survey, Vol. XI, p. 148.
†Maryland Geol. Survey. Vol. IV, p. 222.
‡Geol. Survey of Alabama, Bull. No. 6, p. 43.

of the color in many of the different clays. The following are some of the mineral species of iron with their compositions:

Limonite ($2Fe_2O_3$, $3H_2O$).
Hematite (Fe_2O_3).
Magnetite (Fe_3O_4).
Siderite ($FeCO_3$).
Pyrite (FeS_2).

Limonite is an oxide of iron with water, or a hydrous oxide, which is found occurring in a number of different forms in many of the clays. It is the cause of the yellow or brown color in many of them. According to Ries* in some cases where the clay is uniformly colored the limonite is evenly distributed through the clay and sometimes simply forms a thin film on the surface of the grains. In some clays it occurs as small rusty grains while in others it may occur in concretionary or nodular masses. In some Washington clays it is also found in thin layers or crusts extending through certain parts of the bed. In some cases it may form a considerable part of the mass. Limonite is a soft mineral but a very stable one resisting atmospheric agencies well.

Hematite is an iron oxide also, but does not have water as does the limonite. It is red in color and is the cause of the deep red color of some clays. It is not as stable a compound as the limonite and has a tendency when exposed to the air in the presence of moisture to take on water and change to limonite.

Magnetite is sometimes found in black magnetic particles in clays. Some of the igneous rocks contain grains of magnetite disseminated through them and when these rocks decompose to form clays the little particles of magnetite not being decomposed, especially in the case of the residual clay, are left disseminated through it. Magnetite, as its name implies, is magnetic, has a higher specific gravity than either limonite or hematite, and is black in color. This, like hematite, may change to limonite.

Siderite is the carbonate of iron and it is found in some clays

*Geol. Survey of New Jersey, Vol. VI, p. 45.

and especially in shales, in the form of concretions which vary much in size and shape. Ries* gives three ways in which the carbonate of iron may occur in the clays as follows: (1) As concretionary masses of variable size and shapes, often strung out in lines parallel with the stratification of the clay. These are more abundant in shales than in clay, and, if near the surface, the siderite concretions change to limonite on their outer surface. (2) In the form of crystalline grains, scattered through the clay and rarely visible to the naked eye. (3) As a film coating other mineral grains in the clay. This mineral has usually a brownish color and changes, on exposure to atmospheric agencies, to limonite.

Pyrite is another iron mineral that occurs in some clays. This is the sulphide of iron in which one atom of iron has united with two atoms of sulphur. (FeS_2). It is yellow in color and has a metallic lustre. One of the very common forms in which this mineral occurs is that of cubes. It may occur also in a number of other forms.

This mineral, like some of the other iron minerals, is not a very stable compound, and on being exposed to the atmospheric agencies, changes to an entirely different substance. The sulphide (FeS_2) will take oxygen from the water that percolates through the clay and change to a sulphate ($FeSO_4$). This is a white substance that is soluble in water and may be taken into solution and removed if the water flows through the clay but as a general thing much of it remains as a sulphate in the clay.

The above minerals are the principal sources of the iron found in the clays but sometimes iron may be furnished by other minerals such as biotite, glauconite, and hornblende or in fact by any mineral that contains iron.

Effects of Iron Compounds.—Iron is the principal coloring agent in clays, either burned or unburned. As already stated the limonite is brown or yellow and this is the cause of the brown or yellow color of many clays. The red color found in many clays

*Geol. Survey of New Jersey, Vol. VI, p. 45.

is due to the hematite, while, according to Ries,* the green color found in some clays is due to the silicate of iron. The color in the ordinary blue clays is due largely to a ferrous iron or organic matter. The intensity of color is not always an indication of the amount of iron present in a clay as there may be other substances present, which will mask more or less the iron color.

The physical condition of the iron will have much to do in determining the color of the clay and to be most effective the iron must be finely divided and evenly distributed through the mass of the clay.

Coloring Action of Iron Oxide on Burned Clay.—No matter in what form the iron occurs in the clay on burning, in the presence of oxygen, it will change to a ferric oxide unless the temperature is raised high enough to produce vitrification, and in this case complex silicates would be formed. According to Ries,† the color and depth of shade produced by iron in burning clays will depend on, "1st, the amount of iron in the clay; 2d, the temperature of burning; 3d, condition of the iron oxide, and 4th, the condition of kiln atmosphere."

Clay perfectly free from iron will burn white. When a very small amount of iron is present a yellow color will be produced and as the amount increases the color will change to a buff and then to a red. Five per cent. of oxide will usually cause a clay to burn red.

The temperature at which a clay is burned is an important factor in determining the burned product. A clay containing a small amount of iron when burned at a low temperature may be light colored while if the temperature is increased enough the color may become a fine deep red.

Iron occurs in two different forms known as the ferrous and ferric state; when oxygen, for instance, unites with iron we have ferrous oxide (FeO) in which one atom of oxygen unites with one atom of iron, or we have ferric oxide (Fe_2O_3) where the ration between the iron and the oxygen is one of iron to one and one-half of oxygen. In the ferric condition the iron is more

*Geol. Survey of New Jersey, Vol. VI, p. 57.
†Geol. Survey of New Jersey, Vol. VI, p. 57.

highly oxidized than it is in the ferrous. In the iron minerals described above the limonite and the hematite contain the iron in the ferric condition while the magnetite contains both the ferrous and ferric iron and the siderite and pyrite contain the ferrous form of the iron. Under proper conditions these forms of iron may be changed quite readily from one to the other.

In the burning of clays in which there is ferrous iron present it is necessary that there should be air enough admitted to the kiln to supply oxygen to change this iron from the ferrous to the ferric condition. Again, in the case of a clay in which there is a considerable amount of organic matter and which contains ferric iron if the air is excluded so that the organic matter cannot get what oxygen it needs from this source it will take it from the iron and change it to the ferrous condition. This same result may be brought about by a smoky fire also.

The effect of these two forms of iron on the burning clay has been shown to be different, ferrous oxide alone giving a green color while the ferric oxide alone may give purple or red and mixtures of the two may produce yellow, cherry red, violet, blue, and black while combinations of ferric oxide with silica produce a yellow or red color in the burned clay.*

Since oxidation, as described above, effects the color of the burned clay, the condition of the atmosphere in the kiln is a very important factor in producing the color of the burned ware. When there is a good draft in the kiln and the flame in it has a bluish color, there is an excess of oxygen present and the flame is said to be an oxidizing one and the tendency of such a flame would be to change the ferrous iron to ferric. On the other hand if the draft is poor and the atmosphere in the kiln becomes smoky and the flame is of a yellowish color it will have a reducing effect and will tend to take oxygen from substances with which it comes in contact and in this way ferric iron may be reduced to ferrous iron.

Clays which contain the sulphide of iron (FeS_2) pyrite or marcasite in any very large quantities are not, as a rule, suit-

*Ries, Geol. Survey of New Jersey, Vol. VI, p. 58.

able for any of the better grades of clay wares. When heated the mineral changes from FeS_2 to FeS and on being heated to a higher temperature the compound is broken up, the iron taking up oxygen and forming ferrous oxide (FeO) and the sulphur uniting with the oxygen to form a gas SO_3. This gas may escape from the kiln or in the presence of moisture may unite with water and form sulphuric acid (H_2SO_4) which is capable of dissolving certain of the substances that occur in the clay especially the lime and the magnesium carbonates. These dissolved substances may be deposited on the surface of the ware and perhaps discolor it. This same result may be brought about by using fuel in burning the ware that is high in sulphur.

Fluxing Action of Iron Oxide.—Iron oxide acts also as a fluxing agent in clays and lowers the fusion point. According to Ries* its power as a flux "will be more pronounced if the iron is in a ferrous condition or if silica is present. A low iron content is, therefore, desirable in refractory clays, and the average of a number of analyses of these shows it to be 1.3 per cent."

The following table, showing the range of ferric oxide, in different kinds of clay, as determined from a number of clay analyses, is from the same authority:†

AMOUNT OF FERRIC OXIDE IN CLAYS.

KIND OF CLAY	Minimum	Maximum	Average
Brick Clays	0.126	32.12	5.811
Fire Clays	0.01	7.24	1.506
Kaolins	.....	6.87	1.29

From the above it is seen that the amount of iron in the clays varies a great deal, in some cases being very high and still the clay may be used for certain purposes. Clays, however, that are to withstand a high degree of heat or are for the manufactre of white or light colored ware must not have a very large per cent. of iron. The amount of iron that may be present in any clay and the clay still be suitable for a given purpose will

*Geol. Survey of New Jersey, Vol. VI, p. 59.
†Geol. Survey of New Jersey, Vol. VI, p. 56.

vary somewhat on account of the fact that the other constituents of the clay will vary.

LIME.

Lime is a very common constituent of clays, in some cases occuring in considerable quantities. There is quite a large number of minerals that contain calcium and any of these may furnish the lime to the clays. The presence or absence of lime in a clay and its amount are very important factors in deciding the uses for which any clay is suitable. Lime may occur in the clays either in the form of carbonite, as calcite, as a silicate as in the case of anorthite or oligoclase, or as a sulphate as gypsum.

The carbonate of calcium or calcite is a constituent of many clays and it may occur in very small particles disseminated throughout the clay or it may occur in grains large enough to be distinguished with the naked eye and when this is the case the grains are translucent and tend to be rhombohedral in shape on account of having well marked cleavage in three different directions. The mineral is quite soft being easily scratched with a knife and readily decomposed by water when it has an acid reaction. Its presence may usually be detected by the addition of a few drops of cold diluted hydrochloric acid to the clay when the calcite will be readily dissolved with effervescence. Calcium carbonate may also occur in clays as concretions. These have probably been formed by a process of concentration the lime having been taken into solution by percolating water and then redeposited in certain places.

Effect of Calcium Carbonate on Clay.—In the finely divided condition calcium carbonate is an important factor in determining the refractoriness of clay. On heating it looses carbon dioxide (CO_2) and forms quicklime (CaO). When clay containing calcium carbonate is burned the clay loses its water as well as the carbon dioxide. The carbon dioxide of the calcite as stated by Ries* probably passes off between 850 deg. C. (1,562 deg. F.) and 900 deg. C. (1,652 deg. F.) while the water of hy-

*Geol. Survey of New Jersey, Vol. VI, p. 60.

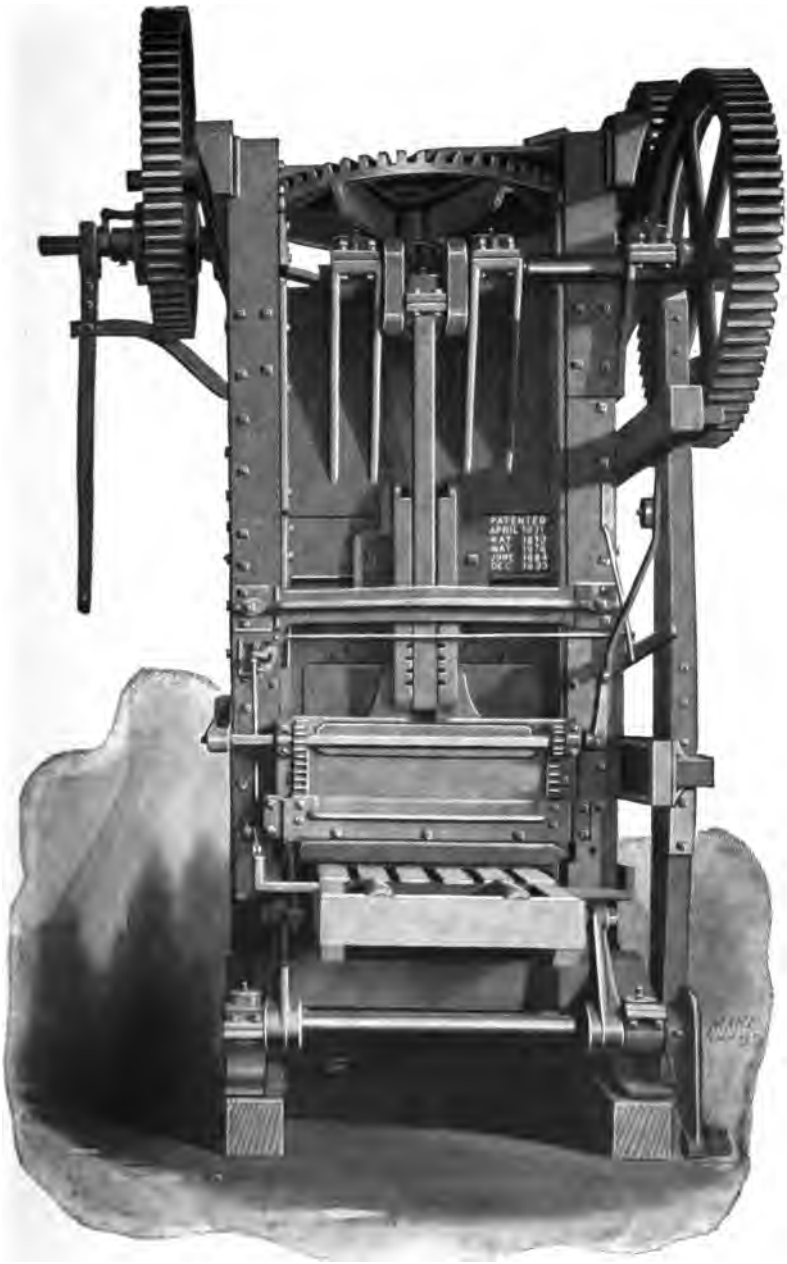
dration escapes at between 450 deg. C. (842 deg. F.) and 600 deg. C. (1,112 deg. F.). This will produce from the calcareous clays a more porous mass, up to at least a temperature of 900 deg. C. (1,652 deg. F.) than from other clays. If, in the burning of the clay, the temperature is not high enough to fuse it and is high enough to drive off the carbon dioxide then the calcite will be changed to quicklime (CaO) and this on exposure of the ware to the atmosphere will take up moisture and slake. In this process expansion takes place and if the lime is not finely divided, but occurs in lumps in the clay or burned ware, it may split the bricks or cause blistering and small pieces to flake off.

If in the burning the temperature is high enough to fuse the clay the result is an entirely different one. In this case a complex silicate will be formed by the lime uniting with silica and we have a silicate of lime, alumina, iron, etc., formed within the clay. The effects of this combination as given by Ries* are as follows:

"In the first place, the lime tends to destroy the red coloring of the iron and impart instead a buff color to the burned clay. This bleaching action, if it may be called such, is most marked where the percentage of lime is three times that of the iron." "Another effect of lime, if present in sufficient quantity is to cause the clay to soften rapidly, thereby sometimes drawing the point of incipient fusion and viscosity within 41.6 deg. C. (76 deg. F.) of each other. This rapid softening of calcerous clays is one of the main objections to their use, and on this account also, it is not usually safe to attempt the manufacture of vitrified products from them, but as mentioned under magnesia, the presence of several per cent. of the latter substance will counteract this. It has also been found possible to increase the interval between the points of incipient fusion and viscosity by the addition of quartz and feldspar."

Clays with a large amount of calcium carbonate require, as a general thing, less water to make them into a workable mass than do other clays. They also shrink less on burning than other clays. The amount of calcium carbonate allowable in a clay will be determined somewhat by its condition, that is whether it

*Geol. Survey of New Jersey, Vol. VI, p. 61.



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is finely divided and intimately mixed with the clay or whether it occurs in lumps through the clay. In the first case a clay containing as much as 20 to 25 per cent. may be used while in the latter condition this much lime might be very injurious.* Again such clays would be suitable only for certain purposes. While they might make good common brick, common earthenware, roofing tile and things of this character, they would not be suitable at all for vitrified brick or vitrified ware of any kind.

Effect of Lime Bearing Silicates.—These are much less important than the lime carbonate. They are less common and less abundant and as they are not broken up into volatile and non-volatile substances by heat, as the carbonate is, they do not effect the shrinkage as does the carbonate. The calcium having already united with silica does not form quicklime as it does in the case of the carbonates, so there is no danger from this source. The silicate would act as a flux in the same way that the carbonate does but would perhaps not produce quite so rapid softening of the clay.

Effect of Calcium Sulphate on Clay.—The sulphate occurs in clays as gypsum. This is the hydrous calcium sulphate ($CaSO_4$, $2H_2O$). Many of the different rocks from which the clays are formed contain more or less pyrite or iron sulphide which, as has already been shown, may be under certain conditions changed to ferrous oxide (FeO) and sulphuric acid (H_2SO_4). The sulphuric acid would then unite with some of the calcium carbonate in the clay and with water form calcium sulphate or gypsum. In the burning of the clay the gypsum, when a temperature of 250 deg. C. is reached, is decomposed to calcium sulphate and water or plaster of Paris and water. As the temperature in the kiln is increased, finally the calcium sulphate will be broken up into calcium oxide (CaO) and sulphurous acid (SO_3), and this latter in escaping from the ware may cause blisters or even in some cases cause the product to crack.

The following table taken from Ries'† report on the New

*Ries, Geol. Survey of New Jersey, Vol. VI, p. 62.
†Geol. Survey of New Jersey, Vol. VI, p. 54.

Jersey clays shows the variation in the amount of lime found in clays that are being used for the production of certain grades of ware:

AMOUNT OF LIME IN CLAYS.

KIND OF CLAY	Minimum	Maximum	Average
Brick Clays	0.024	15.88	1.513
Pottery Clays	0.011	9.80	1.088
Fire Clays	0.030	15.27	0.655
Kaolins	Trace	2.58	0.470

MAGNESIA.

Magnesia occurs in some clays, but is usually present only in small amounts. It may occur in the form of a carbonate, silicate or sulphate. It is a constituent of some of the micas and of hornblende, both of which may be found in clays. As a silicate of magnesia it acts as a flux much the same as the silicate of calcium does. It is not, however, so violent a flux as calcium silicate. It is rare that it is found in this form in great enough quantity to have much effect.

The magnesia, like calcium, commonly occurs in clays in the form of the carbonate and in the majority of cases probably occurs with the calcium carbonate forming the double carbonate of calcium and magnesium or dolomite. This mineral may occur in the clay either in a finely divided state dessiminated through the clay or in crystals and in concretions and masses.

The hydrous sulphate of magnesia in some clays, like gypsum, has probably been formed by the decomposition of iron sulphide to produce sulphuric acid which has united with the magnesia and water to form hydrous magnesium sulphate. This is a readily soluble substance and may form a coating on the ware when drying.

According to Ries* the effect of magnesia on clays when subjected to heat is to act as a flux but it does not cause the clay to soften so rapidly as calcium does and separates the point of incipient fusion and viscosity. It also has a less bleaching effect on the iron.

*Geol. Survey of New Jersey, Vol. VI, p. 64.

The following table shows the range of magnesia in several classes of clays as given by Ries.*

AMOUNT OF MAGNESIA IN CLAYS.

KIND OF CLAY	Minimum	Maximum	Average
Brick Clays	0.02	7.29	1.062
Pottery Clays	0.05	4.80	0.85
Fire Clays	0.02	6.25	0.512
Kaolins	Trace	2.42	0.223

ALKALIES.

The alkalies are found in greater or lesser amounts in all clays. The common alkalies are the potash and soda. These may occur in a number of combinations, the most common, however, is in the form of the silicates and is usually some of the feldspar minerals, but may be other minerals and especially muscovite. Orthoclase is the principal source of the potash (K_2O). This mineral contains 16.9 per cent. of potash. The principal sources of the soda (Na_2O) in the clays are the plagioclase or lime-soda feldspars. The amount of soda in these feldspars ranges from 4 to 12 per cent. depending on the species These latter feldspars fuse at a lower temperature than the orthoclase. The orthoclase occurs more frequently in clays than does the soda-lime feldspars. Analyses of clays usually show the presence of both potash and soda with the potash present in the greater abundance. Ammonia is probably present also in some raw clays, but as this volatilizes very easily when the clay is heated it would be driven off at a very low temperature, and hence, would have no effect on the burning of the clay.

The range of total alkalies found in clays is shown in the following table:†

AMOUNT OF TOTAL ALKALIES IN CLAYS.

KIND OF CLAY	Minimum	Maximum	Average
Kaolins	0.1	6.21	1.01
Fire Clays	0.048	5.27	1.46
Pottery Clays	0.52	7.11	2.06
Brick Clays	0.17	15.32	2.768

*Geol. Survey of New Jersey, Vol. VI, p. 6. Ibid. p. 67.
†Ries, New York State Museum, Bull. 35, p. 515.

The alkalies act as very powerful fluxes and in the form of silicates are desirable constituents of clays except those desired for refractory purposes. In combinations with silica, as feldspars, the alkalies will exert their effect as fluxes at different times in the burning of the ware on account of the fact that the feldspars fuse at different temperatures due to variation in composition. Orthoclase, the potash feldspar, fuses at a temperature of about 2,102 deg. F., and would have its greatest fluxing power at a temperature a little above this, while the soda varieties fuse at even lower temperatures than this, and would therefore become active fluxes before the orthoclase. The feldspars at fusion temperature soften slowly, and on this account would be of value in clays from which vitrified products are to be made. One of the essential properties of a good clay from which to make vitrified ware is that the temperature at which the clay begins to soften and the temperature of complete fusion be as far apart as possible or at any rate that there should be a considerable interval between the two. This being true it is very desirable to have in the clay such fluxes as will produce this result, and on account of their effect in this respect clays containing feldspars are desirable for producing vitrified wares while those that contain any very large amount of lime as already shown are not desirable. They evolve no gas when heated and, hence, do not produce puffing of the wares. They are easily controlled in their actions, bind the particles together in a dense, solid, hard body and permit of the burning of many wares at a lower temperature than would be possible if they were not present. In the manufacture of certain kinds of ware such as porcelain and white earthenware feldspar is a very important flux as it gives to the ware its impervious body on account of fusing easily.

According to Ries* the alkalies have little or no influence on the color of the burned ware. In some instances, however, potash may deepen the color of a clay containing iron.

Muscovite, or white mica, contains potash and when present

*Geol. Survey of New Jersey, Vol. VI, p. 69.

in a clay would be another source of this alkali. This, however, would not become active as a flux at as low a temperature as the other alkalies, as mica takes a higher temperature to fuse than do the feldspars. The temperature at which muscovite fuses has been shown to vary with the size of the flakes and the smaller these are the lower the temperature at which it will fuse.* Even when finely divided, however, the temperature at which muscovite will fuse is considerably higher than the fusing point of the feldspars. The minerals which furnish the alkalies to the clays are complex silicates which fuse at different temperatures and this in connection with the size of the particles or grains would determine the temperature at which the alkalies would act as a flux on the clay.

There has been considerable difference of opinion as to how much alkali may be present in a fire clay and not be positively damaging. Mr. Geo. T. Snelus† says that, "it is found that the presence of alkalies in sensible quantity, say about one per cent. confers so much fusibility upon the clay as to render it unsuitable for very high temperatures."

Cook‡ makes the following statement in his report on the clays of New Jersey:

"Clays containing from two to three per cent. of potash are said to stand well high temperatures. The most carefully made analyses of the more noted and best fire clays of this country and Europe, do not generally show more than two per cent. of potash, and the greater number do not contain one per cent. of alkalies. So far as the clays of this state (New Jersey) have been tried, those which are found to have one and one-half to two per cent. and upwards of potash, have not proved to be good fire clays, and none containing over two per cent. are in use as fire clays. And yet they are otherwise rich and tolerably pure clays. The potash alone appears to explain their low refractory power."

TITANIUM.

Titanium is found in some clays, especially fire clay, in small amounts, but is not usually determined in making chemical

*Trans. Am. Ceramic Society, Vol. IV, p. 255.
†Jour. of the Iron and Steel Inst. 1875, p. 513.
‡Geol. Survey of New Jersey, clays 1878, p. 295.

analyses. Very little work has been done so far to determine the effect of titanium in clays. It is known, however, that, in small amounts even, it acts as a flux and if present in any considerable amounts it will become an active flux. At high temperatures it produces a deep blue color in the burned product. This, however, will be destroyed by a few per cent. of silica.*

The titanium probably occurs usually in clays in the form of rutile, which is titanium oxide (TiO_2) and contains 60 per cent. of metallic titanium and 40 per cent. of oxygen. It is a constituent of some of the igneous rocks and as it is not readily decomposed by the atmosphere, when these rocks decompose, it remains scattered through the clay. Titanium may also occur in the form of the mineral ilmenite, which is an oxide of iron and titanium, and like rutile occurs in small quantities in some of the igneous rocks. The amount of titanium in most clays is so small, however, that its effects are not of any great importance.

ORGANIC MATTER.

Organic matter in greater or lesser amounts is found in many clays. This may occur in a very finely divided condition or in fragments of carbonaceous material. It is a very common constituent of the shales. The organic matter in some clays is a very prominent factor in giving to them their color in the unburned state. The blue and black colors of some clays are due to organic matter and these same clays may on burning become a deep red, the organic matter being destroyed and the iron which was present, but was hidden by the organic matter, gives its color to the burned ware. Clay which contains a large amount of organic matter may burn white on account of the reducing action it would have on the iron in the clay. If, however, this clay is heated gradually, at first, until the organic matter has a chance to pass off and then is heated to a higher temperature and held there for some time the iron will oxidize to ferric iron and give a red color to the product. A considerable amount of organic matter present in a clay may act as quite an important source of fuel in the burning of the

*Ries, Geol. Survey of New Jersey, Vol. VI, p. 71.

products made from such clays. This organic matter is usually consumed at about red heat and on account of this being a point in the progress of burning the ware where the regulation of the temperature of the kiln is very important the organic matter if present in a considerable amount may cause great trouble. The amount, however, is usually so small that no difficulty is experienced from this source. Organic matter has a tendency to increase the absorptive power of a clay for water and probably also effects plasticity. Just what effect it does have on this property of a clay has not been very definitely determined as yet.

WATER IN CLAY.

Water occurs in clays either as water that is an essential part of some mineral and hence chemically combined, or as water that is simply held mechanically by the clay and spoken of as moisture.

The moisture in a clay consists of that which is held in the pores of the clay and that which adheres as a thin film to the surface of each grain of the clay. The amount of moisture in clays varies within wide limits being in the case of some air dried clays according to Ries* as low as .5 per cent., while in those freshly taken from the bank it may reach 30 or 40 per cent. The water in the pores of a clay is absorbed by the clay only when the clay is brought in contact with the water and hence would be given off again when the clay is exposed to the air. The moisture surrounding each grain of the clay as a thin film is readily absorbed from the atmosphere and readily given off again also so that the amount of this moisture may vary at different times on account of different atmospheric conditions. As stated by Ries†, "The amount of either kind of moisture present in a clay depends on the number and size of the spaces between the clay grains, the size of the clay particles, and the amount of organic matter present."

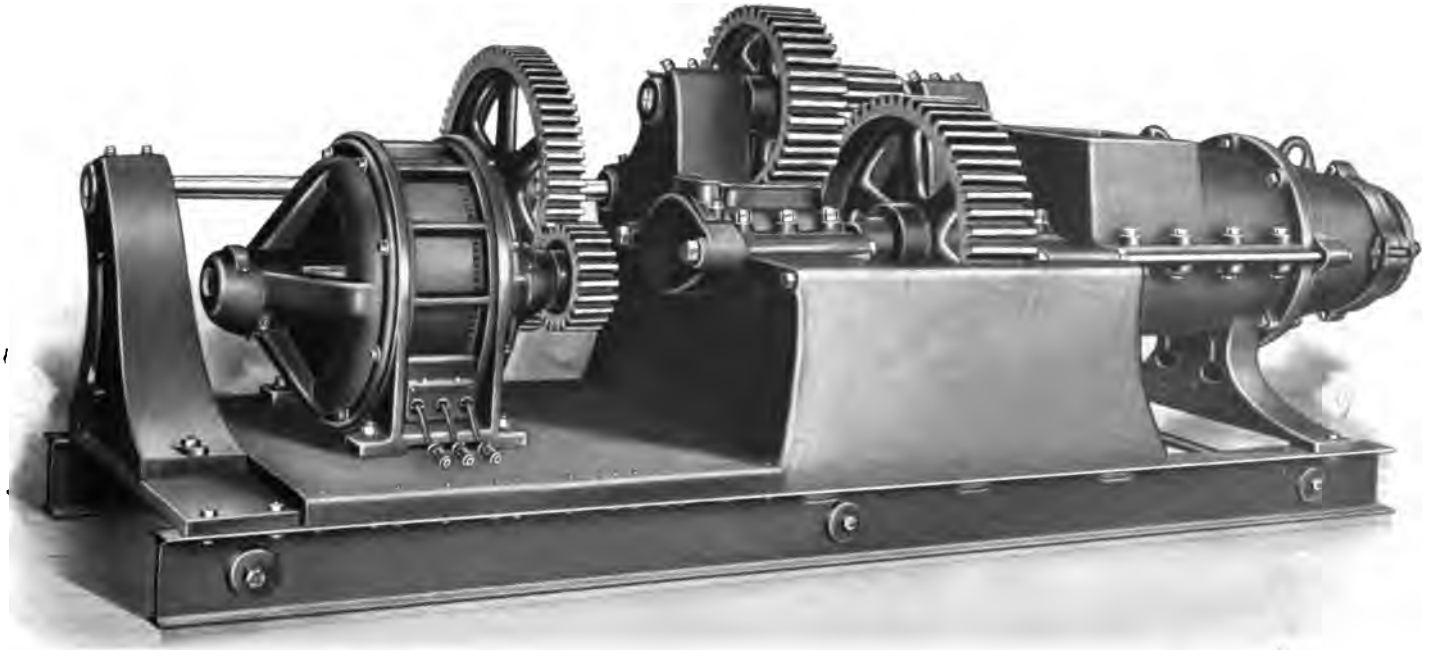
Air drying of clays as a general thing causes the evaporation of most of the moisture or mechanically combined water which

*Maryland Geol. Survey, Vol. IV, p. 245.
†Maryland Geol. Survey, Vol. IV, pp. 246-247.

they contain, and hence will produce a shrinkage of the clay. This shrinkage, however, will cease as soon as the clay particles come in contact with each other and the spaces between these particles may still be filled with water. The moisture may all be completely driven off at 100 deg. C. The amount of shrinkage of clays in drying varies within quite wide limits and may be from 2 per cent. to as much at 15 per cent. In general the coarse sandy clays will shrink the least and the highly plastic clays will shrink the most. Moisture may be injurious in bringing to the surface of the molded ware any soluble salts that may be in the clay. The salts would be taken into solution in the water, brought to the surface with the water, and when it evaporated they would be deposited. This may often be seen in the walls of buildings where the bricks in their manufacture have had soluble salts formed in them and the rain water soaks into the brick and takes these substances into solution and brings them to the surface and when the water evaporates they are left as a coating on the walls.

The chemically combined water is an essential constituent of all clays. This, however, will vary more or less within certain limits. The source of this combined water is the hydrous minerals which compose the clay, and as these minerals vary the amount of this water would vary also. In pure kaolin there is 13.9 per cent. of water and clays are found in which the amounts will vary from this to as low as 3 or 4 per cent.

The chemically combined water is driven off in the burning of a clay and like moisture causes the clay to shrink, the amount of shrinkage depending on the amount of water present. Clays from which this combined water has once been driven off are no longer capable of being made plastic.



MOTOR DRIVEN AUGER BRICK MACHINE, THE AMERICAN CLAY MACHINERY COMPANY.

CHAPTER V.

PHYSICAL PROPERTIES OF CLAY.

The physical properties of clay are the most important things in determining whether it can be used by man for various purposes or not. We may know the chemical composition of a clay and still not be able to say definitely whether it is suitable for a certain purpose or not. Clays that are used, and are well adapted, for a given purpose may vary much in chemical composition. Then, again, of two clays having the same chemical composition one may be well suited for a given purpose while the other is not at all suited for the same purpose. Some of the physical properties of a clay may be told from a chemical analysis, but most of them can be told only by physical tests. In the examination of a clay to determine its value for any particular purpose it should be subjected to physical tests and if these do not give conclusive evidence as to its adaptability for this particular purpose then a chemical analysis should be made. In anything like a thorough study of a clay both chemical analyses and physical tests should be made.

The following, which are considered the most important of the physical tests, will be discussed in this chapter and when a given term may apply to the raw clay or the burned ware the two will be discussed together:

Structure	Plasticity
Color	Shrinkage
Feel	Porosity
Slaking	Specific gravity
Strength	Fineness of grain
Bonding power	Fusibility

STRUCTURE.

The structure and conditions of occurrence of a bed of clay are of importance in determining the method to be used in the

removal of the clay from the bank and its preparation for molding. Clays may have a number of different structures such as slaty, shaly, laminated, and concretionary. These, with the exception of lamination, all indicate changes which have taken place in the clay since its formation. These slates and clays when they were deposited were loose, uncompacted beds and they have been brought into their present condition by the forces of nature, pressure perhaps being the most important one. Clay is ordinarily structureless or massive with often a more or less well developed joint structure. The hard and non-plastic flint clays have a characteristic conchoidal fracture.

The condition of the clay as it occurs in the bed will determine the method to be used in preparing it for molding, and hence will determine at least partly the kind of machinery to be installed for this purpose. The primary object of grinding and tempering the clay is to destroy any natural structure that it may have as it is essential that the body of the clay ware be structureless or as nearly so as possible.

COLOR.

Clays may be found having almost any color. Hydrous silicate of alumina, or kaolinite, when pure, is white but when it contains iron as it usually does it may be red, yellow, brown, or orange. The common clays may be red, black, yellow, blue, gray, and all shades between. The clays are usually colored by iron in some of its various compounds, organic matter, and sometimes by manganese. The iron is usually the cause of the red, brown, and buff colors in the clays and this may, in some cases at least, be the cause of the black, blue, and gray shades found in clays; these latter, however, are more often due to organic matter.

The color of the raw clay, is not always, by any means, an indication as to what the color of the burned product will be. If the raw clay is red in color on account of having iron present the burned product will probably be red. This, however, is not true in all cases for if at the same time there should be pre-

sent a large amount of calcium carbonate the clay might burn buff in color. If the color of the raw clay is due to carbonaceous matter it will indicate very little if anything at all as to what the color of the burned product will be, as the organic matter is combustible and will be consumed in the burning and the minerals that are present will then exert their influence and color the burned ware. The variety of colors in the burned clays is not so great as it is in the raw clays. The white, reds, buffs, and yellows are common colors; the reds and buffs being due to ferric oxide in different proportions and in different states of division and distribution. By some it is claimed that clay containing a large amount of alumina and a small amount of iron oxide will, when burned, on account of the formation of certain iron aluminum compounds, produce yellowish colored ware. This effect of alumina, however, has been questioned by some, and Orton* has shown that the iron alumina ration may vary greatly and still the clay burn to the same buff color.

FEEL.

The feel test is the one that is first applied to ascertain the texture and plasticity of a clay. The texture of the clay may be tested roughly by rubbing the dry powder between the fingers and by taking it between the teeth, the presence of any grit or grains of sand may be detected. Many of the fat, plastic clays when dry have a soapy or greasy feel when rubbed with the fingers. Others, again, which are coarse grained or sandy, do not have this "slick" feel, but are harsh and rough. Some clays are very unctuous and these are said to be fat. A fat, tough, plastic clay when mixed with water may be easily molded in the hand into various shapes and forms without cracking while the lean clays can not, hence the feel may be a very valuable field test in determining plasticity.

SLAKING.

Slaking is that property that certain substances have of separating into flakes or small particles when brought in contact

*Trans. Am. Ceramic Soc., Vol. V, p. 389.

with water. When a piece of air-dried clay is placed in water it begins to swell a little and more or less slowly crumble to pieces. The fine grained clays will break up into very fine particles and as these small particles keep breaking off from the outside of the clay mass, new surfaces are exposed and finally the whole is disintegrated. The different clays and shales vary much as regards the rate at which this slaking takes place and in fact shales will not slake at all or at any rate the action is so slow that it is of no practical importance as regards these shales. In some cases if the shales are ground then they may be effected by the water. In some cases shales will disintegrate into a more or less lumpy mass which usually has to be pulverized and agitated in water to completely break it into its constituent particles.

In the working of a clay the question of slaking is of considerable importance. A clay that will take up water readily and break into very fine particles may be brought into a plastic, moldable condition with less work, and hence, less expense than one that must be pulverized before the water appears to have any effect on it. In actual practice clays are often dug from the pit and left in piles out in the open air exposed to the atmospheric agencies for a greater or less time to weather. The conditions under which weathering takes place may be entirely different from those necessary for slaking. In weathering small amounts of water constantly supplied may be a very effective agent in breaking up the clay, while to cause slaking the clay should be air-dried, the water added suddenly, and in greater amount than the clay can absorb. Clays may often be made to work more readily if spread out where they are exposed to atmospheric agencies, where they will become dry and then when rain comes may be exposed to these, or where they may be wet occasionally from a hydrant. In this way in addition to being broken to pieces they may be purified somewhat by having certain soluble salts washed out of them.

TENSILE STRENGTH.

This is the property of a clay that enables it to resist being pulled apart when air-dried. This is a very important physical

property of a clay and on account of this property we are able to use clays in many ways that otherwise we could not. This property is much higher for clays than for most other substances after they have been as finely divided as the clays are. This property varies within wide limits in the different kinds of clay, being in some cases as high as 400 pounds, while in others it may be only a few pounds. Clays also have a considerable strength in the wet condition and a knowledge of both of these is of importance to the clay worker as they have a practical bearing on the molding and handling of the ware. The greater the tensile strength of the wet clay the better the freshly molded ware will retain its shape in handling and the less danger of loss from this source. High tensile strength in the air-dried clay is important also as in burning, the ware that is at the bottom of the kiln must support the weight of all of that above it. Then if it has a low tensile strength there will be more loss on account of breaking when handling.

It used to be thought that tensile strength and plasticity were closely related to each other and that as plasticity varied the tensile strength would vary also. This view at the present is not very generally accepted. Ries* says, "There may be some relation between the plasticity and the tensile strength of a clay, but it is neither a constant nor a simple one. While high tensile strength and plasticity often go together, there are marked exceptions. A clay low in tensile strength may yet have high plasticity, as is seen in the case of some New Jersey clays, and, on the other hand, however, a clay of only moderate plasticity may have high tensile strength."

PLASTICITY.

This property is the one that makes it possible to mold the clay when wet into any form or shape desired. Plasticity is thus a property that is characteristic of wet clays and which allows them while in this condition to be formed into the different shapes and sizes found in the clay wares in use at the present time. This is the most important property of a clay and with-

*Geol. Survey of New Jersey, Vol. VI, p. 83.

out this it would be of little value for the manufacture of the ordinary clay products. Clays show a very wide range as regards this property some being very plastic while others are but slightly plastic. These very plastic ones are known as "fat" clays while the non-plastic or but slightly plastic ones are spoken of as "lean" clays. Sandy clays are apt to be lean. Some clays which contain a large amount of clay substance are also lean.

As has been shown by certain persons* the property of plasticity is not peculiar to clays alone, but is found to a greater or less extent in other substances. Some of these, such as lead and wax, are plastic in their natural condition, while others, as sands, are slightly plastic when water is present. This property of plasticity, however, while it may be present in other substances is much more highly developed in the clays, when they are wet, than in other materials.

The amount of water necessary to develop the greatest amount of plasticity in a clay will vary and ranges from about 14 per cent. in the case of the coarse clays to as high as 30 to 35 per cent. in the case of the very fine clays as the kaolins.†

The table given below shows the range in the amount of water necessary to develop the maximum plasticity in the Missouri clays:‡

WATER REQUIRED TO DEVELOP MAXIMUM PLASTICITY.

Kind of Clay.	*Per Cent.*
Loess or brick clays	16.0 to 19.0
Fire and potters' clays	15.0 to 33.0
Flint clays	15.0 to 24.0
Kaolins	18.0 to 35.0
Shales	14.0 to 25.0

Many different theories have been advanced to explain the cause of plasticity in clays, but no one of them appears to be entirely satisfactory. One of the oldest theories is the one based on the fact that all clays contain more or less water, chemically combined with the different minerals which make up the clay, and when this is driven off by heating the clay it is no

*Ries, Clays, Occurrence, Properties and Uses, pp. 94-95.
†Wheeler, Geol. Survey of Missouri, Vol. XI, p. 97.
‡Wheeler, Geol. Survey of Missouri, Vol. XI, p. 98.

longer plastic and so far it has not been possible to restore this plasticity. On account of this many have concluded that this water is the cause of plasticity. There are a number of things that go to show that this water which is an essential constituent of some of the minerals in the clays is not the cause of their plasticity.

In the first place, there are a large number of other minerals which are hydrous silicates of alumina, and some of which are very closely related to kaolinite, that are not plastic. Some of these may even contain more water than kaolinite and still they are not plastic. Then, again, some clays may contain a very large amount of clay substance or kaolinite, and hence a large amount of water and still be much less plastic than another clay which contains much less kaolinite and hence less water. In heating clays so as to drive off the chemically combined water, plasticity is destroyed but it is thought by some that this is due to physical changes in the clay. Ries* in discussing this point says, "That a temperature necessary to drive off the water of combination may also break up other structures closely related to the plasticity."

Texture Theory.—The texture or fineness of the grain of a clay has been advanced by some as a cause of plasticity. Whitney† in his work on soils calls all particles that are less than .005 of a mm. in diameter clay particles. If the size of the particles composing the mass of the clay is the only thing that determines whether a clay is plastic or not then other mineral substances if finely pulverized, should be plastic. Experiments have been performed with such substances as quartz and calcite by Wheeler‡ who found that when they were ground so as to pass a 200 mesh sieve they appear to be appreciably plastic, but when dried the coherence was very slight, and they could hardly be handled without falling to pieces. Professor Orton|| performed experiments along the same line using glass which was

*Clays Occurrence, Properties and Uses, p. 96.
†Mechan. Anal. of Soils, Dept. of Agric., Bur. of Soils. Bull. 4, p. 15.
‡Missouri Geol. Survey, Vol. XI, p. 102.
||Brick, Vol. XIV, No. 4, p. 216.

ground so fine that it would float in water for an indefinite time and found that it had practically no plasticity. These experiments show that while some little plasticity may be developed in substances like glass and sand by very fine grinding yet they never become plastic like good clays. Many of the non-plastic flint clays are fine grained and if plasticity were due to size of the grains in a clay these should be very plastic. From the above it would seem that plasticity cannot be accounted for on texture alone.

Plate Theory.—Johnson and Blake* found on making a careful study microscopically of a number of different clays that they were made up very largely of small transparent plates and prsmatic crystals. In most of the clays examined by them the plates were found to be very abundant and in some cases they were grouped together in bundles. They make the following statement as regards plasticity:

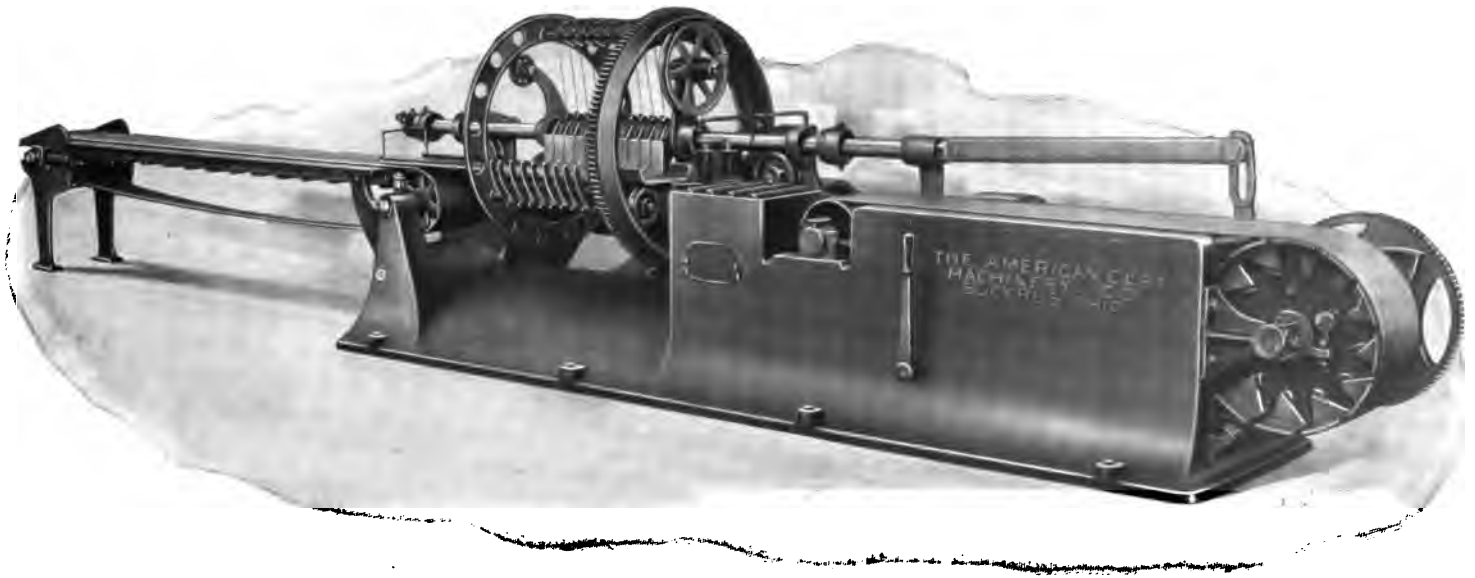
"The plasticity of clay is a physical character and appears to have a close connection with the fineness of the particles. The kaolinite of Summit Hill, consisting chiefly of crystal plates averaging .003 of an inch in diameter, is destitute of this quality. The nearly pure kaolinite from Richmond, Va., occurring in bundles of much smaller dimensions, the largest being .001 of an inch in diameter is scarcely plastic."

These same clays, they state, became plastic when they were triturated in an agate mortar and the bundles of plates broken up. They also suggest that perhaps the shape of these plates may have some effect on plasticity.

Haworth in his study, microscopically, of the Missouri clays found very much the same things to be true as had Johnson and Blake. The clays which were most plastic he found to be composed of minute scales and "that mere fineness, per se, had no bearing on plasticity, but that the condition and amount of the plates present had a very important bearing."†

*Am. Jour. Science, (2) pp. 351-361, 1867.

†Missouri Geol. Survey, Vol. XI, p. 104.



CUTTING TABLE, THE AMERICAN CLAY MACHINERY COMPANY

Wheeler* sought to prove this point by means of the following experiments:

"Slate when ground finely, was slightly plastic or possessed appreciable strength when dry, while, when ground to an impalpable powder it possessed plasticity with considerable strength on drying.

"Iceland spar (calcite) which has a perfect, coarse platelike cleavage, was moderately plastic when finely ground, and when very finely ground possessed a strength of from 50 to 100 pounds to the square inch.

"Prophylite, a scaly, hydrous silicate of alumina, was plastic when wet, but very tender when dry, but it was difficult to grind it very fine on acocunt of its greasy nature. Talc is a similar greasy mineral with a coarsely lamellar structure. It was plastic when wet but had no strength when dry.

"Gypsum is a brittle mineral, with coarsely lamellar structure that can be readily pulverized to a very fine powder; it was decidely plastic when finely ground, and when finely pulverized was very plastic or had a strength of 250 to 350 pounds on drying.

"Hallyosite, a massive mineral with a conchoidal fracture, was found to have a plate structure under the microscope, but in close groups or clusters; it was decidedly plastic when finely ground or had a strength of about 150 pounds when very finely ground."

From the above experiments and from his study of clays he concluded that the plate or minute scale theory explains the cause of plasticity of the clays better than any other so far advanced.

Other persons have attributed plasticity to other causes such as the interlocking of grains, and more recently what is known as the colloid theory has been advanced by certain observers. Ladd,† as a result of his work on the Georgia clays, advocated the theory of mutual attraction between the water and clay particles and surface tension acting on the free surfaces of the water in the clay as being the principal factor in the cause of plasticity.

*Missouri Geol. Survey, Vol. XI, p. 106.
†Geol. Survey of Georgia, Bull. 6A, p. 31.

From the above it would appear that plasticity is not satisfactorily explained in all cases by any one of these theories alone, but that several of them together and perhaps others that we know nothing about at present are the cause of this very important property of the clays.

SHRINKAGE.

Shrinkage has reference to loss of volume and as applied to the manufacture of clay products is of two kinds, air shrinkage or that caused by the drying of the ware, and fire shrinkage, or that produced by the burning of the ware.

Air Shrinkage.—In a clay which contains no water, the grains which compose the clay are all in contact with each other. These grains, however, vary in shape and size and hence there would be more or less spaces left between them and when the clay is brought in contact with the water it is absorbed until these spaces are filled without changing its volume. After these pores have been filled with water if more is absorbed it causes an increase in the volume or swelling of the clay. After the pores are filled the additional water which the clay absorbs is supposed to be in the form of a film surrounding each grain of clay. This causes the grains to be separated more or less and decreases the attraction between them and when enough is added it will practically overcome this attraction and the clay will no longer retain its shape when molded. The amount of water which a clay will absorb will vary a great deal and an instance is given by Geo. P. Merrill* of a clay which absorbed water enough so that it had eight times its original bulk.

When a clay has been mixed with water and molded into whatever form is desired, this water begins to evaporate. As the evaporation goes on the particles composing the clay begin to come closer together producing more or less shrinkage of the mass. This will continue until all of the water, which occurs in the clay as films around the grains, has passed off and the grains have come in contact with each other. When the grains have all

*The Non-Metallic Minerals, p. 248.

come in contact with each other then the air shrinkage ceases, but the clay may still have moisture left in it. This is due to the fact that the grains are irregular in outline and do not touch each other at all places and hence there are pore spaces in the clay and these hold water which can only be gotten rid of by heating the clay to a temperature of 100 deg. C. On account of this, air shrinkage may cease before the moisture has all passed off. The amount of water held in the pores of the clay will vary from a fractional part of one per cent. to as much as 6 or 8 per cent.

The amount of air shrinkage in general is greatest in the fine grained clays and least in the coarse sandy ones the latter in some cases being as low as 1 per cent. The amount of this air shrinkage will also vary with the amount of the water added in tempering the clay. Brick molded by the soft mud process would shrink more in drying than those made by the stiff mud process from the same clay.

This question of air shrinkage is a very important one in the actual working of a clay. In the drying of the molded ware if the water be allowed to escape too rapidly it may cause the ware to shrink unevenly and warp and it may also produce cracking. In the case of the fine grained clays, a too rapid escape of the water may cause the outside to shrink faster than the interior and unless the clay has a high tensile strength it may crack. The coarse grained sandy clays may be dried more rapidly than the fine grained ones. This is due to the fact that the coarse grained ones contain larger pores than the fine grained ones, and hence allow the water to escape more rapidly and more evenly. The air shrinkage begins as soon as the clay is molded and at first takes place quite rapidly but gradually decreases with time, and is usually completed before the ware is placed in the kiln.

The rapidity with which this drying may be done becomes of practical importance as regards the facilities for drying necessary to handle the amount of brick or ware of any kind molded in a given time. Sand and grog, or burned clay, may be added to fine grained clays making them more porous, and hence allowing them to be dried more rapidly. This will also

cause them to shrink less, and there will also be less danger from warping and cracking.

The effect of sand on air shrinkage is well shown in the following table*. The lower row of figures shows the effect of the addition of 50 per cent. of sharp sand to a clay from near Herbertsville, New Jersey.

TABLE SHOWING EFFECT OF SAND ON THE AIR SHRINKAGE AND TENSILE STRENGTH OF CLAY.

Per cent. of water required.	*Per cent. of air shrinkage.*	*Tensile strength lbs. per square in.*
32.6	5.3	108
15.6	3.3	65

The effect of the sand as seen from the above was to reduce the amount of water required to make it plastic almost one-half; the air shrinkage was reduced 37.73 per cent. and the tensile strength 39.81 per cent.

Fire Shrinkage.—Almost all clays shrink more or less in the process of burning. The amount of this shrinkage, like air shrinkage, varies a great deal in different clays ranging from 2 or 3 per cent. up to as much as 18 or 20 per cent. and sometimes even more than this. The cause of fire shrinkage is the driving off of the organic matter which the clay may contain, the breaking up of chemical compounds, and volatilizing of certain substances as the water in the hydrous minerals which occur in the clay and perhaps small amounts of carbon dioxide from the carbonates that may be present. When a high enough temperature is reached some of the substances in the clay begin to fuse and these flow into and fill the pores of the clay and this will cause still further shrinkage. According to Ries† the "fire shrinkage begins at a dull, red heat, or about the point at which chemically combined water begins to pass off, and reaches its maximum when the clay vitrifies, but does not increase uniformly up to that point." The amount of fire shrinkage depends upon the amount of the volatile substance present in the clay, the porosity of the

*Ries, Geol. Survey of New Jersey, Vol. VI, p. 92.
†Clays, Occurrence, Properties and Uses, p. 129.

clay and the fusibility of it. Quartz which is a common constituent of clay has a tendency to counteract this fire shrinkage and in some cases may even cause the clay to expand in burning. At high temperature the quartz expands and if the amount of this is large, this small amount of expansion of the individual grains may in the aggregate be sufficient to equal and in some cases exceed the total shrinkage of the other minerals in the clay and thus produce expansion. The quartz also decreases the plasticity and tensile strength so that only certain amounts can be added to a clay without injuring it.

Wheeler* claims that one of the most important factors in producing fire shrinkage "is the size of the grain; the finer it is the greater the shrinkage. The amount of sand or free silica present is a less important factor in diminishing the amount of shrinkage, but other things being equal, the more sand the less shrinkage, though the coarseness of the sand is much more important than the amount, as the coarser the sand the less the shrinkage. The amount of lime and magnesia present as carbonate is very important in reducing the shrinkage, which influence is felt when they exceed 2.0 per cent. and increase until they exceed 15.0 per cent., when the shrinkage is eliminated. As they are usually present as silicate, which has no noticeable influence in shrinkage, they do not often have to be considered, as it is exceptional to have them present as carbonates."

This question of shrinkage in clays is an important one from the manufacturer's standpoint. Knowing the amount of shrinkage that will occur in the drying and burning of a clay, the manufacturer is able to tell how large his ware must be molded so as to have a given size when burned. In all clay ware that is made to specific size the amount of shrinkage must be determined carefully and an allowance made for this. The amount of shrinkage varies so much in different clays that each one must be tested separately under the same conditions that it will be subjected to in actual working. They should be ground to the same degree of

*Missouri Geol. Survey, Vol. XI, p. 121.

fineness that will be used in actual working, the same amount of water mixed with them to give the same plasticity, and finally burned at the same temperature and under the same conditions that will be used in actual practice. The less the shrinkage of a clay, other things being equal, the more valuable it will be. Mixtures of two or more different clays may be used in such proportions as to decrease the amount of shrinkage. Sand, crushed quartz, burnt clay, crushed brick and pottery, are all used to reduce the shrinkage of clays by being mixed with them in different amounts.

POROSITY.

Clays are more or less porous; the amount of this porosity depending on the size and shape of the grains composing the clay mass. The greatest amount of pore space or porosity in a body will be obtained by having the particles of which it is composed spherical and of uniform size. In clays the grains vary in size and are irregular in shape. It is very evident that if this is true, that these particles composing the clay cannot be in contact with each other at all points, even when the clay is in its most compact condition. That the particles are not actually in contact with each other at all points is shown by the fact that clays absorb water up to a certain amount without expanding and if they were not more or less porous they would not do this. The microscope shows that the shape and size of these particles vary a great deal.

Porosity is of practical importance on account of the fact that it determines the amount of water the clay will absorb and in this way determines the amount of air shrinkage. By some the rate at which a clay absorbs water has been taken as indicating the amount of porosity, the one absorbing most rapidly being considered the most porous. This is no indication of the amount of porosity, as two clays may differ in texture and have the same amount of pore space, the one with the larger pores would absorb water more rapidly than the one with the smaller pores, but in time both would absorb the same amount.

The clay with the large pores would also allow the water to

escape more rapidly and allow the molded ware to dry more rapidly. Small pores would have a tendency to retard evaporation and hence drying.

Porosity is also a very important factor in determining the value of the burned ware as it determines the amount of water that it will absorb. Unless thoroughly vitrified all burned ware is more or less porous. In the case of paving brick, for instance, a high porosity, and hence the power of absorbing a large amount of water, is injurious. The maximum amount of water that a good paving brick will absorb may vary somewhat, but should never be large and by many 3.5 per cent. is given as the extreme. Some paving brick, that by actual use, have proven very satisfactory absorb as high as 5 per cent. of water. The tendency would be for all porous wares when exposed to the atmosphere to break to pieces by the pores filling with water and if this should freeze it would expand and separate the clay particles. The size of the pores would have much to do with the amount of disintegration brought about in this way, and other things being the same, it would be the least in the brick having the largest pores.

SPECIFIC GRAVITY.

The specific gravity of a clay is a property which apparently is not of any very great practical importance. It has to be known in determining the porosity of a clay, according to certain methods. By some specific gravity is considered as a physical condition of a clay and a function of porosity, and according to this conception it would have a bearing on the fusibility of the clay. According to this view it has been shown* that the specific gravity would be a constantly varying quantity, being different when the clay comes from the bank from what it would after it had been ground and in fact it would change with each change of manipulation.

The true specific gravity of a clay does not depend on its density, but rather upon its composition and hence would be con-

*Iowa Geol. Survey, Vol. XIV, p. 114.

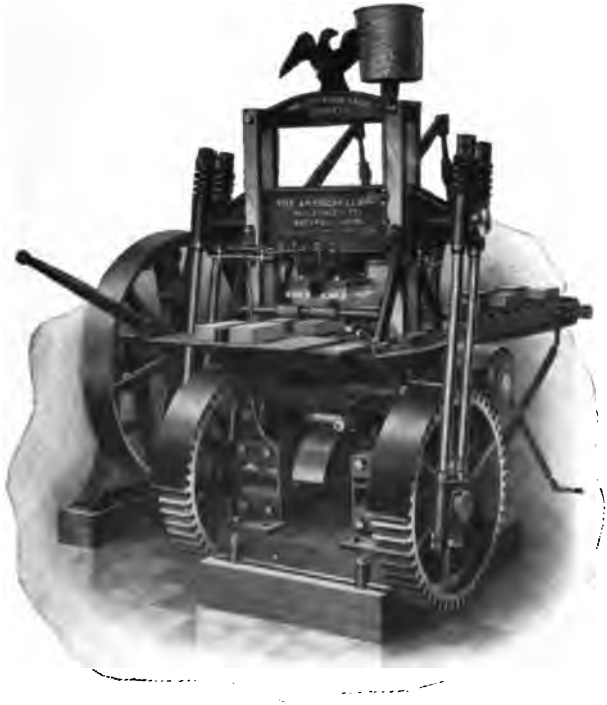
stant for any given clay. The different minerals which are most abundant in the clays do not vary any great amount in specific gravity. Pure kaolinite has a specific gravity of 2.6, quartz has a specific gravity of 2.65, feldspars 2.55 to 2.75, the micas 2.7 to 3.1 and calcite 2.71. The iron oxides would be heavier than any of the above, but they usually form a very small part of the clay. The specific gravity of clay will vary within certain limits on account of the fact that its mineralogical composition will vary, but as shown above, this variation should not be very great and in general the specific gravity of the clay should not be far from that of kaolinite which, in most cases, composes the larger part of the clay.

In a series of Iowa clays, tested by Byer and Williams,* the specific gravity varied from 2.32 to 2.64. The New Jersey clays, tested by Ries,† gave specific gravities ranging from 2.34 to 2.84. In the Missouri clays, tested by Wheeler,‡ the specific gravity was found to range from 1.66 to 2.64. The low values obtained by Wheeler are probably due to the method used and the fact that he does not consider specific gravity as depending on mineralogical composition, but on physical condition and mainly on density. The specific gravity, as determined by Wheeler, would constantly vary and would be of very little value even as a means of comparison.

FUSIBILITY.

The temperature at which a clay fuses or changes from a solid to a liquid condition is an important one in determining its adaptability for certain purposes. All clays will fuse at some temperature. Every mineral, if pure, and under the same conditions, has a definite temperature at which it will fuse. This will usually be different for different minerals and may be in the case of a mixture of minerals different from that of any single mineral composing the mixture. In this case the minerals act as

*Iowa Geol. Survey, Vol. XIV, p. 116.
†New Jersey Geol. Survey, Vol. VI, p. 114.
‡Missouri Geol. Survey, Vol. XI, pp. 562-573.



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a flux on each other and the mixture may fuse at a much lower temperature than any single mineral in it.

Clays are mixtures of minerals, each having a definite composition and as already stated a fairly well defined melting point of its own. The amount of these minerals in a clay will vary, no two clays having exactly the same proportions. If such a substance be subjected to a gradually increasing temperature the results are quite different from what they would be in the case of a simple substance or a single mineral. The single mineral, when the proper temperature is reached, would liquify at once. The clay would act in quite a different way. As the temperature gradually increases a point is reached where the most fusible substances will begin to melt or liquify. This liquid material which occupies and partially, at least, fills the pores in the unfused material would begin to act partly as solvents of the unfused minerals and as this is continued with increase of temperature finally the whole of the clay would be melted. The influence that one mineral has on another in the fusion process is a very difficult one to determine, and one that is not very well understood as yet. It is known that certain substances, when in contact with each other, fuse at entirely different temperatures from that at which either one will fuse by itself. In some cases, in all probability, chemical action takes place and new substances are formed. In others this appears hardly probable and it is apparently more a case of solution, or the dissolving of one substance by another.

On account of the gradual softening of clays when heated to the point of fusion Wheeler* proposed the following terms for the three most important stages:

1. *Incipient Vitrification.*—In this stage the individual grains can no longer be recognized, the clay has almost completed its shrinkage, and has attained a hardness of from 6.0 to 6.5. There has been enough softening of the grains so that they stick together well.

*Missouri Geol. Survey, Vol. XI, p. 130.

2. *Complete Vitrification.*—The clay in this stage has been heated from 100 deg. to 300 deg. F. above what it was in the other. The density is somewhat increased by a still further slight shrinkage, the hardness has increased from 6.0 to 7.0, and the grains have softened so much that they have completely lost their individuality and have run together so as to completely close up the pores in the mass. The clay is still stiff enough, however, to retain its form. The fracture is now smooth and has a slight luster.

3. *Viscosity.*—If the clay be heated from 100 deg. to 400 deg. F. still higher it swells and softens, and finally becomes liquid enough to flow and change its form.

In actual practice it is often very difficult to recognize when these three different conditions have been reached and the change from one to the other is often a very gradual one. In some cases it may be quite sudden. The temperature necessary to change a clay from one of these conditions will vary with the composition of the clay. In clays which contain a considerable amount of calcium carbonate, for instance, the difference in temperature between the point of incipient vitrification and viscosity as given by Ries* may be as low as 27.7 deg. C. (50 deg. F.) while in the refractory clays it may be as much at 277 deg. C. (500 deg. F.).

As it is not possible to regulate the temperature of the kiln in burning within very narrow limits it becomes of considerable practical importance that the points of incipient vitrification and viscosity be well separated. In the case of all ware that is to be vitrified this is especially important. In this case if the point of incipient vitrification and that of viscosity are only a few degrees apart there would be danger of either not getting the temperature high enough to completely vitrify the ware or, of getting it so high that viscosity would be reached and much of the ware ruined by melting.

Effect of Chemical Composition on Fusibility.—Other things being equal, the less of those substances that act as fluxes, such

*Clays, Occurrence, Properties and Uses, p. 139.

as iron, lime, soda, etc., that a clay contains the more refractory it will be or the higher the temperature necessary to fuse it. Pure kaolinite is a very refractory substance requiring a temperature of 1,830 deg. C. to fuse it. Along with the kaolinite are usually found more or less impurities which act as fluxes on it. The effect of these impurities as already stated in general is to lower the fusing point of the clay. The amount of this lowering of the fusing point of the clay is not the same, for a given amount of these different substances. That is, some are stronger fluxes than others, and it requires more of one than of another to produce a given result. The different fluxes also fuse at different temperatures and hence the times when they would become active would vary through a considerable range.

Among the first to make experiments along this line was a German, by the name of Richters, who formulated his results into the following laws:*

1. "The refractory quality of a clay of any given proportion of silica and alumina is most influenced by the fluxes in the following order: MgO, CaO, FeO, Na_2O, K_2O.

2. "Chemically equivalent quantities of these oxides exert equal influences on the refractoriness of a given clay. That is, 40 parts of magnesia, 56 parts of lime, 72 parts of ferrous oxide, 62 parts of soda, 92 parts of potash, will each produce an equal degree of fusion in the same quantity of the same clay.

3. "If a number of fluxes are present in a clay, the fusibility produced will be proportional to the sum of their chemical equivalents. For example, a clay with the formula,

$$\left.\begin{matrix}.15K_2O\\.15CaO\end{matrix}\right\} Al_2O_3, 2SiO_2$$

should fuse at the same temperature as one of the composition,

$$\left.\begin{matrix}.1K_2O\\.1CaO\\.1FeO\end{matrix}\right\} Al_2O_3, 2SiO_2."$$

*Iowa Geol. Survey, Vol. XIV, p. 130.

These laws were worked out by Richters using a series of alumina silica mixtures and known portions of the fluxes were then added to these. He experimented in one case with silica and alumina in the proportion in which they occur in kaolinite while in the other he used a higher percentage of silica.

Silica and alumina, when in the proportion in which they occur in kaolinite, fuse at cone 35 or at about 1,830 deg. C. As the proportion of silica is increased the temperature at which fusion will take place will be gradually lowered until the ratio Al_2O_3, $17SiO_2$ is reached. The silica up to this point then has acted as a flux to the alumina. Now, if a still higher percentage of silica be added the temperature at which fusion takes place will be higher. On account of the fluxing effect of silica at high temperatures it should not be present in excess in refractory clays. The presence of silica also, according to Ries,* has a tendency to intensify the action of other fluxes.

Experiments have been carried on to try to verify the laws given above, by Cramer of Berlin†. He found they are true only as regards kaolinite and that in the presence of free silica the fluxing power of the oxides was as follows: FeO, MgO, CaO, Na_2O, K_2O. That is in a clay that contains free silica chemically equivalent quantities of the fluxes do not produce equivalent effects, 72 parts of ferrous oxide being able now to do more work than 40 parts MgO or 56 parts of CaO and so on.

It should be understood that these laws will hold true only when each of these fluxes in the mixture is enabled to exert its maximum influence. Each of these different fluxes will have a definite temperature at which it will fuse and each will be different and as they do not begin to act until the point of fusion is reached they would come into action at different times and for them all to exert their maximum influence a temperature high enough to fuse the whole mass would be necessary. This being the case the laws would not hold strictly in the burning of a clay as the ware in the kiln is not completely fused.

*Clays, Occurrence, Properties and Uses, p. 141.
†Iowa Geol. Survey, Vol. XIV, pp. 131-132.

Effect of Physical Conditions on Fusibility.—The two principal things, in connection with the physical condition of a clay which effect the fusibility of it are homogeneity and the texture, or size and shape of the grains composing it. In order for any substance to be able to exert its greatest influence it should be evenly distributed throughout the mass so that all parts may be alike. Clays, as they occur in nature, are seldom homogeneous, the constituent minerals of which they are composed being segregated more or less and separated from each other. In such cases, if the different minerals are all desired in the manufacture of the ware, they must be mixed artificially, and the mass made as nearly homogeneous as possible.

Other things being equal, the finer the particles of which a clay is composed the more readily it will fuse. This is due partly, at least, to the fact that in the clay which is made up of fine particles, these come closer together, and hence the spaces between the particles and across which the heat must be transmitted are less. The clay fuses by each little particle of which the mass is composed becoming highly heated and melting on the outside and then as the heat penetrates into each particle, finally the whole of it is liquified or melted. Now, if the readily fusible substances in the clay occur in very small particles they fuse more readily and hence begin sooner to exert their fluxing effect on the other substances. In the fine grained clays the heat is more evenly distributed throughout the mass. The clay, being composed of minerals that fuse at different temperatures and more or less porous, fuses gradually and the more fusible substances, when the temperature becomes high enough to melt them, will occupy the spaces between the less fusible ones and the finer the grains, other things being equal, the more nearly will this fused material fill these spaces and completely surround the more refractory particles.

Hoffman* has shown, for clays which require above about 1,650 deg. C. to melt them, that the size of the grain has practically no effect on their fusibility.

*Am. Inst. of Min. Eng., Vol. XXVIII, pp. 440-444.

The shape and variation in size are also of some importance in determining the temperature at which a clay will fuse. If the grains are angular in outline, they are more apt to come close together and would have smaller spaces between the particles than if the grains are spherical. Then if the grains are of various sizes, the small ones may fill the spaces between the larger ones making the clay more dense and hence a better conductor of heat.

As far as the physical condition of the clay is concerned then the finer the grains or particles of which it is composed, the more irregular in outline these particles are, and the greater the range in size below the largest of these particles the more favorable the condition for fusion.

Condition of Oxidation.—The amount of oxygen, according to some, appears to have an influence on the temperature at which a clay fuses. Ries* makes the following statement in regard to this point:

"Finally it is found that the same clay will fuse at a lower temperature, if in burning it is deprived of oxygen, than it will if burned in an atmosphere containing plenty of the latter."

This fact may be of some practical value in the burning of some clays. In some cases a considerable amount of oxygen in the atmosphere in the kiln is essential.

Expression of Fusibility.—Having a knowledge of the relative values of the different fluxing elements in clays and their effect on the fusibility of clay several different investigators have attempted to express the relative fusibility of clays by the relation of the fluxes to the refractory substances found in them. Among the earliest of these investigators were Bischof and Seger, German scientists, who developed formulas for this relation. These have not proven very satisfactory as they do not take into account the physical condition of the clay besides neglecting a number of very important things in connection with the composition. Wheeler† in his report on the clays

*Clays, Occurrence, Properties and Uses, p. 145.

†Missouri Geol. Survey, Vol. XI, p. 149.

of Missouri suggests a formula for expressing the relation of what he calls the detrimental and non-detrimental constituents of a clay. This he calls the fusibility factor. This formula, on account of taking into consideration, partially at least, the physical condition of the clay and on account of the fact that he took into account the different fluxing values somewhat, of the different substances, is the most satisfactory one so far advanced.

None of the formulas are entirely satisfactory and are of little practical use. They all require a chemical analysis of a clay before they can be applied and this is no small job in itself, and an actual test as to fusibility may be made much easier.

Methods of Measuring Fusibility.—The means of measuring fusibility may be divided into two classes known as the direct and the indirect. The first depends on determining or estimating the degree of temperature needed to actually fuse a given clay. For the direct determination of temperatures two methods are in general use, one of which is by means of some form of apparatus or mechanical pyrometer. The principal of these pyrometers depends on the expansion of gases or solids, measurement of electric currents, analysis of light emitted from a heated object, etc. The second of these is by means of test-pieces of known composition, and hence a known fusing temperature.

There are a number of different forms of these pyrometers on the market, but what is known as the Le Chatilier pyrometer is one of the best. This is based on the principle of generating an electric current by heating a thermo electric couple consisting of two wires, one of pure platinum and the other of alloy of platinum with ten per cent. of rhodium. A small porcelain tube surrounds one end of one of these so that the ends of the wires cannot touch. An end of each wire is then placed in a larger porcelain tube, one end of which is closed. The other ends of the wires connect with a galvanometer which may be so graduated as to read degrees Centigrade. The temperature of the kiln is then measured by placing the porcelain tube containing the wires in it and reading the amount of deflection of the needle

of the galvanometer. The cost and the delicacy of these instruments have tended to prevent their general use.

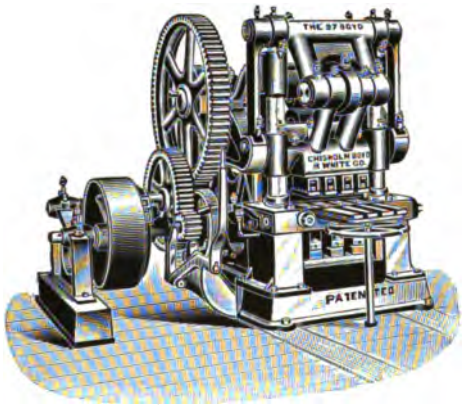
The most common method in use at the present time is by means of a series of test pieces which have a given composition and so arranged that the fusing point of any one is a given number of degrees above the next one. Those most widely used throughout the country are known as Seger cones being so named on account of having been first introduced by H. Seger, a German ceramist.* The materials which Seger used in making these cones were such as would have a constant composition and consisted of Zettlitz kaolin, Rorstrand feldspar, Norwegian quartz, Carrara marble, and pure ferric oxide. This series originally numbered from 1 to 36 inclusive, or from 1,150 deg. C. to 1,850 deg. C. The number of degrees between any two successive cones in this series is 20 deg. C. No. 1 has a melting point the same at that of an alloy composed of one part of platinum and nine parts of gold. No. 20 melts at the highest temperature obtained in a porcelain furnace or 1,530 deg. C., and cone 35 has the composition of kaolin from Zettlitz and fuses at 1,830 deg. C. Other series of these cones which fuse at lower temperatures have been produced by Cramer and by Hecht by the addition of soda, boracic acid, and lead oxide to these cones in the proper proportions until now we have a series of 58 numbers, the fusion point of the lowest is 590 deg. C. and that of the highest 1,850 deg. C. These new series were numbered by prefixing a cipher to each number in the first series.

The composition and fusing points of the different members of the series are given below:†

COMPOSITION AND FUSING POINTS OF SEGER CONES.

No. of cone	COMPOSITION			Fusing Point	
				° F	° C
.022	0.5 Na_2O, 0.5 PbO	.....	2.0 SiO_2, 1.0 B_2O_3	1,094	590
.021	0.5 Na_2O, 0.5 PbO	0.1 Al_2O_3	2.2 SiO_2, 1.0 B_2O_3	1,148	620

*Ries, Clay, Occurrence, Properties and Uses, p. 148.
†Ries, Bull. New York Museum, No. 85, pp. 555-557.



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COMPOSITION AND FUSING POINTS OF SEGER CONES—*Continued.*

No. of cone	COMPOSITION	Fusing Point	
.020	0.5 Na_2O, 0.5 PbO } 0.2 Al_2O_3 { 2.4 SiO_2, 1.0 B_2O_3 }	1,202	650
.019	0.5 Na_2O, 0.5 PbO } 0.3 Al_2O_3 { 2.6 SiO_2, 1.0 B_2O_3 }	1,256	680
.018	0.5 Na_2O, 0.5 PbO } 0.4 Al_2O_3 { 2.8 SiO_2, 1.0 B_2O_3 }	1,310	710
.017	0.5 Na_2O, 0.5 PbO } 0.5 Al_2O_3 { 3.0 SiO_2, 1.0 B_2O_3 }	1,364	740
.016	0.5 Na_2O, 0.5 PbO } 0.55 Al_2O_3 { 3.1 SiO_2, 1.0 B_2O_3 }	1,418	770
.015	0.5 Na_2O, 0.5 PbO } 0.6 Al_2O_3 { 3.2 SiO_2, 1.0 B_2O_3 }	1,472	800
.014	0.5 Na_2O, 0.5 PbO } 0.65 Al_2O_3 { 3.3 SiO_2, 1.0 B_2O_3 }	1,526	830
.013	0.5 Na_2O, 0.5 PbO } 0.7 Al_2O_3 { 3.4 SiO_2, 1.0 B_2O_3 }	1,580	860
.012	0.5 Na_2O, 0.5 PbO } 0.75 Al_2O_3 { 3.5 SiO_2, 1.0 B_2O_3 }	1,634	890
.011	0.5 Na_2O, 0.5 PbO } 0.8 Al_2O_3 { 3.6 SiO_2, 1.0 B_2O_3 }	1,688	920
.010	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.50 SiO_2, 0.50 B_2O_3 }	1,742	950
.09	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.55 SiO_2, 0.45 B_2O_3 }	1,778	970
.08	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.60 SiO_2, 0.40 B_2O_3 }	1,814	990
.07	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.65 SiO_2, 0.35 B_2O_3 }	1,850	1,010
.06	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.70 SiO_2, 0.30 B_2O_3 }	1,886	1,030
.05	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.75 SiO_2, 0.25 B_2O_3 }	1,922	1,050
.04	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.80 SiO_2, 0.20 B_2O_3 }	1,958	1,070
.03	0.3 K_2O, 0.7 CaO } 0.2 Fe_2O_3, 0.3 Al_2O_3 { 3.85 SiO_2, 0.15 B_2O_3 }	1,994	1,090

COMPOSITION AND FUSING POINTS OF SEGER CONES—*Continued.*

No. of cone	COMPOSITION			Fusing Point	
.02	0.3 K_2O, 0.7 CaO	0.2 Fe_2O_3, 0.3 Al_2O_3	3.90 SiO_2, 0.10 B_2O_3	2,030	1,110
.01	0.3 K_2O, 0.7 CaO	0.2 Fe_2O_3, 0.3 Al_2O_3	3.95 SiO_2, 0.05 B_2O_3	2,066	1,130
1	0.3 K_2O, 0.7 CaO	0.2 Fe_2O_3, 0.3 Al_2O_3	4 SiO_2	2,102	1,150
2	0.3 K_2O, 0.7 CaO	0.1 Fe_2O_3, 0.4 Al_2O_3	4 SiO_2	2,138	1,170
3	0.3 K_2O, 0.7 CaO	0.05 Fe_2O_3, 0.45 Al_2O_3	4 SiO_2	2,174	1,190
4	0.3 K_2O, 0.7 CaO	0.5 Al_2O_3	4 SiO_2	2,210	1,210
5	0.3 K_2O, 0.7 CaO	0.5 Al_2O_3	5 SiO_2	2,216	1,280
6	0.3 K_2O, 0.7 CaO	0.6 Al_2O_3	6 SiO_2	2,282	1,250
7	0.3 K_2O, 0.7 CaO	0.7 Al_2O_3	7 SiO_2	2,318	1,270
8	0.3 K_2O, 0.7 CaO	0.8 Al_2O_3	8 SiO_2	2,354	1,290
9	0.3 K_2O, 0.7 CaO	0.9 Al_2O_3	9 SiO_2	2,390	1,310
10	0.3 K_2O, 0.7 CaO	1.0 Al_2O_3	10 SiO_2	2,426	1,330
11	0.3 K_2O, 0.7 CaO	1.2 Al_2O_3	12 SiO_2	2,462	1,350
12	0.3 K_2O, 0.7 CaO	1.4 Al_2O_3	14 SiO_2	2,498	1,370
13	0.3 K_2O, 0.7 CaO	1.6 Al_2O_3	16 SiO_2	2,534	1,390
14	0.3 K_2O, 0.7 CaO	1.8 Al_2O_3	18 SiO_2	2,570	1,410
15	0.3 K_2O, 0.7 CaO	2.1 Al_2O_3	21 SiO_2	2,606	1,430
16	0.3 K_2O, 0.7 CaO	2.4 Al_2O_3	24 SiO_2	2,642	1,450

COMPOSITION AND FUSING POINTS OF SEGER CONES—*Continued.*

No. of cone	COMPOSITION			Fusing Point	
17	0.3 K_2O, 0.7 CaO	2.7 Al_2O_3	27 SiO_2	2,678	1,470
18	0.3 K_2O, 0.7 CaO	3.1 Al_2O_3	31 SiO_2	2,714	1,490
19	0.3 K_2O, 0.7 CaO	3.5 Al_2O_3	35 SiO_2	2,750	1,510
20	0.3 K_2O, 0.7 CaO	3.9 Al_2O_3	39 SiO_2	2,786	1,530
21	0.3 K_2O, 0.7 CaO	4.4 Al_2O_3	44 SiO_2	2,822	1,550
22	0.3 K_2O, 0.7 CaO	4.9 Al_2O_3	49 SiO_2	2,858	1,570
23	0.3 K_2O, 0.7 CaO	5.4 Al_2O_3	54 SiO_2	2,894	1,590
24	0.3 K_2O, 0.7 CaO	6.0 Al_2O_3	60 SiO_2	2,930	1,610
25	0.3 K_2O, 0.7 CaO	6.6 Al_2O_3	66 SiO_2	2,966	1,630
26	0.3 K_2O, 0.7 CaO	7.2 Al_2O_3	72 SiO_2	3,002	1,650
27	0.3 K_2O, 0.7 CaO	20 Al_2O_3	200 SiO_2	3,038	1,670
28	.....	Al_2O_3	10 SiO_2	3,074	1,690
29	.....	Al_2O_3	8 SiO_2	3,110	1,710
30	.....	Al_2O_3	6 SiO_2	3,146	1,730
31	.....	Al_2O_3	5 SiO_2	3,182	1,750
32	.....	Al_2O_3	4 SiO_2	3,218	1,770
33	.....	Al_2O_3	3 SiO_2	3,254	1,790
34	.....	Al_2O_3	2.5 SiO_2	3,290	1,810
35	.....	Al_2O_3	2 SiO_2	3,326	1,830
36	.....	Al_2O_3	1.5 SiO_2	3,362	1,850

In actual practice these cones are of much value. They are mounted on a small block of clay in an upright position and placed in the kiln or furnace with the material to be burned. They should be so placed that they will be under as nearly the

average conditions in the kiln as possible. They should also be so placed that they may be easily observed from the outside through a small opening and so that there may be no danger of cold air striking them. In actual use it is always well to put into the kiln three or four cones of different numbers so that the rate at which the temperature is increasing may be observed. As the melting point of a cone is neared it will gradually soften, the top bend over, and when the tip of the cone just touches the base it is considered to have fused.

In determining what cone to use in the burning of any kind of ware some experimenting has to be done by placing several different numbers in the kiln or furnace along with the ware to be burned and when the ware has reached the proper condition examining the cones to see what the effect has been. For example, we may have had in the kiln cones, numbers .05, 4, and 6. Now if .05 and 4 should be bent over and 6 is not affected, then we know that the temperature was some place between the fusing point of 4 and 6 so that the next time numbers 5 and 6 would be put in and if 5 fused and 6 remained unaffected it would show that the temperature reached the fusing point of 5 and this can be used from this time on to indicate when the ware is burned.

As pointed out by Ries,* the cones are not for measuring temperatures but for indicating when certain results have been obtained. That is if certain changes have been brought about in a clay at the fusing point of a given cone these same changes will occur again when the same cone fuses, although the temperature at which it will fuse may vary within certain limits on account of the fact that the atmospheric conditions in the kiln may be somewhat different at different times. The temperatures given in the table as has been proven by frequent tests with thermo-electric pyrometers are very close to the ones at which the cones actually fuse. When these cones are used it is not a question of temperature but a question of certain changes, and when a given cone fuses these changes have taken place and the kiln is closed down.

*Geol. Survey of New Jersey, Vol. VI, p. 105.

The following table gives approximately the cone numbers used in the different branches of the clay industry in the United States:*

TABLE OF CONE NUMBERS.

Common brick	.012-.01	Hard burned common brick	1-2
Buff front brick	5-9	Hollow blocks and fireproof	.03-1
Terra cotta	.02-7	Conduits	7-8
White earthenware	8-9	Red earthenware	.010-.05
Fire bricks	5-18	Stoneware	6-8

These cones numbered from .010 to 35 may be obtained from Prof. Edward Orton, Jr., Ohio State University, Columbus, Ohio, at one cent each.

The indirect method of measuring the fusibility of clays is not used very much in actual practice. There are a number of these methods that have been advanced by different investigators at different times, the most important of which are those of Bischof and Hoffman, and Demond. The principle of these methods is to mix enough of certain substances with the clay to be tested, to bring it up to a certain standard of fusibility, say cone number 36. The amount of the material needed to make the clay act like the standard would give an idea of its fusibility. This method was used originally mainly for testing highly refractory clays, but some modifications of it have been made so as to apply it to other clays as well.

BONDING POWER.

The bonding power of a clay is defined as its ability to stand the addition of non-plastic matter. Clay which will allow the addition of a large amount of any inert substance, as sand for instance, without seriously affecting its strength, would be said to have a high bonding power. Bonding power may be determined for different clays by mixing with them various amounts of sand, and then determining the strength of the different mixtures. Bonding power and plasticity appear to be closely related, those clays having the greatest plasticity usually having the greatest bonding power.

*Ries, Clays, Occurrence, Properties and Uses, p. 153.

Bonding power of a clay may be of considerable practical value. Sand is often added to a clay to decrease shrinkage, and it is important to know the bonding power so as to know how much sand may be added without injuring the clay. Again, two or more clays are often mixed in actual use for the manufacture of certain articles, one of which is plastic, while the other, as the flint clay, is non-plastic, and in this case the question of bonding power becomes of importance in determining the relative amounts of these that may be used, as the bonding power must not be reduced so much that the clay will not hold its form and stand handling when dry.

Combustible substances as sawdust, coal, straw, or other organic materials, are often added to clays, partly to reduce shrinkage but at the same time they decrease the plasticity, and also the bonding power. These organic substances also act as fuel in the burning of the ware and, as has already been pointed out, on account of combustion taking place at a time when the regulation of the temperature of the kiln is very important, and as a large amount of organic matter would cause a rapid increase of temperature, it might cause an injury to the ware. The tendency of this organic matter would be to produce a porous ware, provided it is not burned to the point of vitrification.

The size of the grains of the material added, as sand, appears to be imported as regards its effect on the bonding power. Prof. Edward Orton, Jr.,* after a considerable number of experiments, has arrived at the following conclusion: "That the non-plastic ingredients of a clay influence its tensile strength inversely as the diameter of their grains, and fine grained clays will, other things being equal, possess the greatest strength."

FINENESS OF GRAIN.

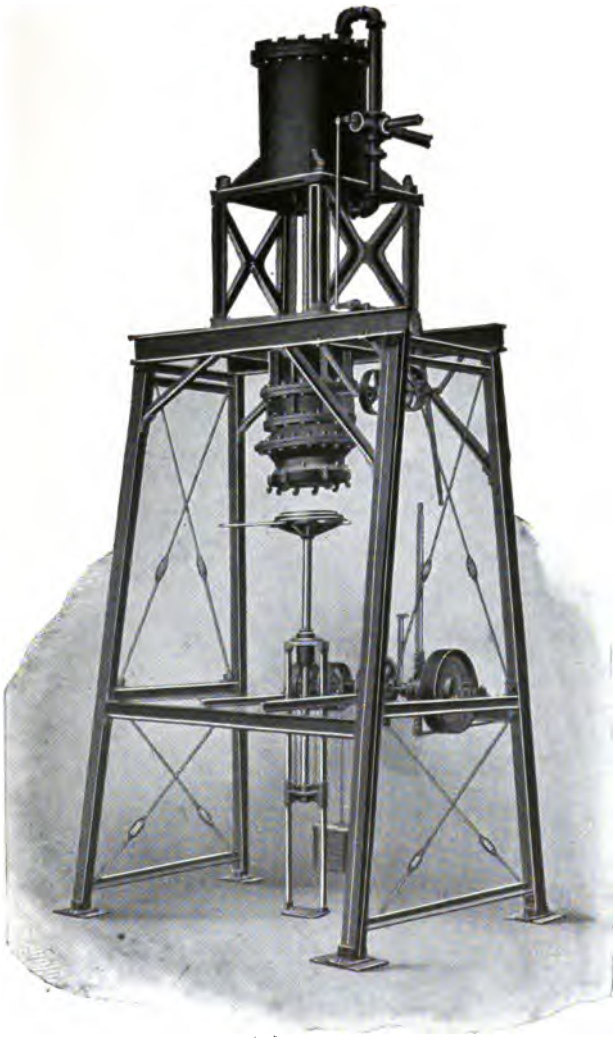
Clay is composed of particles of mineral substances such as kaolinite, quartz, feldspar, etc. In any given clay these particles will vary in size within a wide range, but the relative pro-

*Trans. Am. Ceramic Soc., Vol. II, p. 100; Vol. III, p. 198.

portions of the large and small grains will vary and hence we have coarse and fine grained clays. The size of the grains, as well as the relative proportion of the different sizes, may be determined by a microscopical examination. Mechanical analyses are also made in various ways to determine these same points. Much may also be told as to the fineness of grain by the appearance, the way they slake in water, and by the way the wet clay feels between the fingers. These latter tests are easily made and are of much practical importance to the clay worker.

The size of the grains or the texture of a clay has an important bearing on the plasticity, shrinkage, fusibility, porosity, and the rapidity with which the molded ware may be dried. As has already been shown, the size of the grains, while it does not by itself account for plasticity, appears to have an important bearing on this property, and in general the finest grained clays are the most plastic. In general the fine grained most plastic clays shrink most in drying and burning. The porosity of a clay is also influenced by the size of the grains composing the mass of the clay. The shape of the grains is very important, as is also the range in size. In very porous clays, or at least those in which the pores are large, water will escape more readily than from those in which the pores are small, and hence coarse grained ones may be dried more rapidly than the fine grained ones, and in this way the size of grain or texture may affect the rate at which the molded ware may be dried without being injured. The texture of a clay is also an important factor in the burning of the ware. The temperature of the ware must be brought, in the burning of the clay, to the same temperature as the atmosphere in the kiln which surrounds it. This is brought about by means of conduction. The outer particles of the ware absorb heat from the atmosphere and being in contact with other particles transmit this heat to them. In general, those clays with the finest texture, on account of the particles of which they are composed being packed together more closely and in more intimate contact, are the best conductors of heat. This would tend then

to overcome unequal shrinkage in the burning of clays and the tendency would be greatest in the fine grained clays. The texture is important in determining the rate at which the gases, that may be formed in the burning of the clay, may escape. In a clay with a coarse texture and well defined pore system they escape readily and there is no danger of injury to the ware. From the above it is seen that the texture or fineness of grain of a clay is a very important property.



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CHAPTER VI.

USES OF AND SUGGESTIONS IN REGARD TO PROSPECTING FOR CLAY.

Very few people have any idea of the uses to which clays are put, and the different materials that are made from them, and on account of this, the following table, which gives the principal uses of clays, is given:*

USES OF CLAYS.

"*Domestic.*—Porcelain, white earthenware, stoneware, yellow ware, and rockingham ware for table service and cooking; stoves of majolica; polishing brick, often known as bath brick; fire kindlers.

"*Structural.*—Brick, common, front, pressed, ornamental, hollow, glazed; adobe, terra cotta, roofing tile; glazed and caustic tile; drain tile; paving brick; chimney flues; chimney pots; door knobs; fire proofing; terra cotta lumber; copings; fence posts.

"*Hygienic.*—Urinals, closet bowls, sinks, wash-tubs, pitchers, sewer-pipe, ventilating flues, fountain blocks, vitrified bricks.

"*Decorative.*—Ornamental pottery, terra cotta, majolica, garden furniture.

"*Minor Uses.*—Food adulterants, paint fillers, paper filling, electric insulators, pumps, filling cloth, scouring soap, packing horses' hoofs, chemical apparatus, condensing worms, ink blotters, ultramarine manufacture, emery wheels.

"*Refractory Wares.*—Crucibles and other assaying apparatus, gas retorts, fire bricks, glass pots, saggars, stove and furnace bricks, blocks and fire boxes, tuyeres, cupola bricks.

"*Engineering Work.*—Puddle, Portland cement, railroad ballast, water conduits, turbine wheels."

On account of the very great importance of clay for the manufacture of many kinds of ware, as shown by the above table, a few suggestions will be made here as to the methods to be

*Ries, Maryland Geol. Survey, Vol. IV, pp. 266-267.

applied in prospecting for clay in the hope that they may be the means of helping to develop the clay industry of Washington. These suggestions are made mainly for the people in the different parts of the state who may be interested, in one way or another, in the development of this industry, but who have no knowledge of chemistry, and no practical knowledge of the clay industry.

SUGGESTIONS IN REGARD TO PROSPECTING FOR CLAYS.

The methods to be used in prospecting for clays will depend very largely on the character of the clays sought, that is, whether they are clays that occur on or near the surface, or whether they are such as are apt to be found some distance below it. In the case of those clays that are found on or near the surface they may be prospected for by carefully going over the ground and looking for outcrops, by boring, or by digging pits.

Most areas are more or less rolling, and erosion has done a certain amount of work toward exposing any deposits of clay that may be near the surface. By going over any area of this kind, and making a careful inspection of the entire surface, one may often find good clay deposits, which come to the surface in places. Then there are but few places where streams do not occur, which have cut out channels and gorges, and in this way exposed material which may be some distance below the surface. By following the streams and drainage lines and making a careful examination of all the outcrops along these a person may often find valuable deposits which do not show on the surface, but the stream having cut through the surface material, shows the clay beneath it. On this account, these streams should be carefully followed. In addition to simply showing the presence of the clay, the stream may also show the thickness, as well as the variation in character of the different parts of the bed. The cuts along the road should be carefully examined as these may show clays which are not exposed at other places. Wells, excavations for buildings, and everything of this character should be carefully inspected

as they may be the source of much valuable information. The material brought to the surface by burrowing animals, such as live in the ground, may at times furnish considerable information as to the character of the material below the surface. The occurrence of springs along the hillside at about the same altitude may indicate the presence of a clay seam at that point. Clays are not readily penetrated by percolating water and where a layer of plastic clay occurs a short distance below the surface, which is practically level, water is apt to accumulate and form a marsh or swamp.

The character of the vegetation should be noted carefully as it shows much as regards the character of the soil. In general, the vegetation is scant on clay soils as plants do not thrive on bodies of fat, heavy clay, because in the wet season they have too much water and in the dry season they bake and become too hard to furnish the conditions favorable for the growth of a very large amount of vegetation. Again, the kind of vegetation might indicate the character of the soil.

Clays may be located by boring with an auger and where hard substances such as boulders, gravel, or substances of this nature do not interfere the deposits may be examined to a considerable depth. A two-inch auger is the most convenient, where only small samples are required. This may be operated by one man, and a depth of from twenty-five to thirty feet easily obtained. If larger samples are desired a larger auger may be used but the work becomes more difficult and hence much slower. The augers are most conveniently operated when so arranged as to use gas pipe, screwing on additional joints from time to time as depth is obtained and they are needed. This method may also be used in soft shales, and in plastic fire clays. If the material is too hard and tough for the augers, drop drills may be used, but these are not as satisfactory as the auger.

The method of digging pits is the most satisfactory way of prospecting a clay deposit as it will allow of taking of any sized samples desired, and also permits a personal inspection of the deposits which is not possible by boring. There is always more

or less danger in connection with the work on account of the tendency of the clays to cave. The following statement concerning this point is made by Wheeler:*

"The secret of success in such work is to keep the pit very small, or 30 inches in diameter if possible, selecting the dry season, when the ground is free from water, and pushing the work very fast so as to quickly get down to the deposit; and to rapidly inspect it and obtain samples before the ground begins to work off. This necessitates small sharp tools and experience, when the work is safe and rapid, if in the hands of an expert, but it is dangerous, uncertain, and expensive, if attempted by a novice."

The location of a clay deposit will have much to do in determining whether it has a commercial value or not. At the present time there are many good clays in different parts of the country that are not being used because they are not handy to transportation and will not merit the expense of being hauled for considerable distances by teams. There are so many good clays, for most purposes, which are favorably situated as regards transportation that only the very highest grades of clay, such as kaolin or china clay, and perhaps the best grades of fire clay, will stand the expense of being hauled for any very great distances by teams.

When a clay deposit of good quality is situated in a locality where it may be profitable to work it, one of the first things that should be done is to determine its extent. This may be done in a number of ways, such as boring and digging pits to determine its thickness. Its extent horizontially may be determined in the same way by digging a number of these pits, or by making a large number of borings. Its extent horizontially may also be determined by following outcrops from place to place which may occur in ravines where streams have cut into and exposed them, or where they are exposed in railroad or wagon road cuts. In all of these very careful examination should be made as regards the uniformity of the deposits as clays are liable to vary a great deal even in short distances.

*Missouri Geol. Survey, Vol. XI, p. 552.

The position of a clay bed has much to do in determining its value. In the case of surface deposits, the amount and character of the overlying material, may have much to do with this. If the clay is covered with a considerable thickness of material of no value, but which must be removed in order to work the deposit, it adds just that much more to its cost, and in case this material is hard and difficult to remove this additional cost will be sufficient so that the clay cannot be worked at a profit. Only the best grades of clay will stand the expense of being worked by means of tunnels and slopes. In Washington, at two localities only, is this done, and at these the clays are such as are used for fire brick, sewer pipe, and high grade ornamental brick. There is also more or less danger in this method of working clay deposits, and on this account it is used as little as possible. Surface deposits, which are situated on low ground may be hard to work on account of the water. The plastic clays are practically impervious to water, and if the deposits are so situated that the water will flow into the pits from the surface, it will cause the additional expense of pumping in order to work them, and this might make it impossible to work the deposits at a profit. Conditions should be such, if possible, that the pits may be drained and so avoid the accumulation of water during the wet season. There should, however, be sufficient water obtainable at the minimum cost to supply the needs of the plant.

The location of a plant and the working of any given clay deposit will be determined partly by the question of fuel. The nearness, and hence the cost of the proper kind of fuel may determine whether a clay can be worked profitably or not. The questions of transportation and a market for the manufactured ware are also very important ones. Some kinds of ware may stand shipping a considerable distance, and still sell at a profit, while some other kind would not stand the additional expense of freight charges, and hence could be used only to supply the local demand. The cost of labor is another important factor in profitably working any deposit and must be taken into consideration.

In sampling a clay deposit care should be taken to get an average of the deposit, and as it is very apt to vary in different places, samples should be taken from different parts of it, and then these all thoroughly mixed together. If pits are sunk, samples should be taken from top to bottom, as well as from several pits, at some distance from each other. The sample to be tested should represent the average of the deposit, or at least of that part to be worked. If, however, there are several distinct grades of clay in the deposit, these may be kept separate and tested separately, but in that case each separate grade should be carefully sampled by taking samples from different parts of the deposit. Testing small samples taken from one particular part of a deposit will not establish the character of the deposit as a whole.

In prospecting for clays, materials of value are often passed by unnoticed, on account of the impression that many people have, that clays are the only substances that are suitable for the manufacture of clay wares. For certain uses shales are as valuable as clays, and for some perhaps even more so, and hence the prospector should not overlook these deposits. Not all shale deposits by any means are of value, and a deposit must be sampled and tested much the same as the clay in order to determine whether it is of commercial value or not.

The very highest grades of clay, such as kaolins and china clays, and the best grades of fire clays, are rare, and when found in any quantity and in localities that are at all favorable should be carefully examined. Clays and shales often occur in connection with coal and sometimes are valuable while in other cases they have no value. Some of the best fire clays are hard and flint-like, and break with conchoidal or shelly fracture. It is not possible to recognize fire clays by appearance, actual tests being the only thing that will prove the value of any clay as regards its fire resisting qualities. Analyses may show much as regards the probability of a clay being refractory, but the proof of it is in actually submitting a sample to the action of heat, and seeing what the results are.

Mechanical changes often take place in clay deposits sub-

sequent to their deposition and may have an important bearing on the amount of any deposit and on the method to be employed in working it. The transported materials, when deposited are laid down in a practically horizontal position. Many of the deposits do not occur in that position at the present time. In the uplifting of a bed of clay or shale subsequent to this deposition, it is rare for the whole area to be elevated exactly the same amount, especially if a large area is effected and the beds may on account of this show variable amounts of tilting. In some cases especially where there is a folding of the beds the dip of the deposits may be very steeply inclined. This may effect the value of the deposit on account of giving to it such great depth below the surface in a short distance that it could not be worked profitably. In some cases the dip of these deposits may be 90 deg. or they are vertical and in this case they would be more easily worked than they would if they were not so steep.

Some beds are not sufficiently elastic so that when pressure is applied they will bend, but instead of this they break, and if at the same time the broken ends of these beds on either side of the break are carried past each other faulting occurs. Where the fault plane makes a small angle with the horizontal plane the amount of faulting is apt to be greatest. Faulting has an important influence on the form and extent of the outcropping beds. It may occur in such a way as to expose on the surface a single bed a number of times and make it appear as a number of distinct or separate beds.

The following simple tests taken from the West Virginia Geol. Survey Report* on clays are given here to enable persons not familiar with clays to arrive at an approximate idea at least of the value of any given clay:

1. "A small lump of clay may be roasted in a blue gas flame, as in a gas stove; if a red or brown color be given to the clay, the percentage of iron is high, probably four per cent. or more. Fire clays are low in iron.

2. "By tasting a bit of the clay, bitter salts, alum, epsom, may be detected, or they may occur as white coatings on the out-

*Grimsley, W. Va., Geol. Survey, Vol. III, pp. 90-91.

crops of the clay in the bank. These salts are apt to form whitewash coats on the finished brick, injuring their appearance. By crushing the clay in the mouth the sand may be detected by grit against the teeth. A rough determination of the amount of such sand may be made.

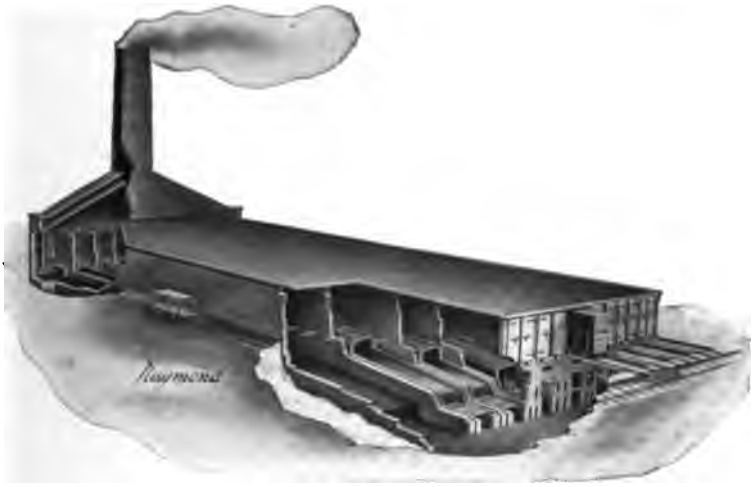
3. "An approximate idea of plasticity may be obtained by working the moist clay with the fingers. This is a good test for pottery clay, moistening the clay and finding whether it can be worked into a definite shape and retain the form when dry without cracking.

4. "A rough brick of small size can be made and easily dried and a rough determination be made of its shrinkage. If it shrinks out of shape, cracks, or crumbles when dry its value is very doubtful. For this test, the clay should be ground, thoroughly tempered with water and dried slowly.

5. "If carbonates of lime are present, a few drops of hydrochloric (muriatic) acid may be added, and it will be detected by the effervescence or bubbling as the carbonic acid gas passes off. A better plan is to place a lump of clay in the small amount of acid, as the clay absorbs the liquid so rapidly the effervescence may be overlooked. Good fire brick are low in lime. If there be low percentage of iron present and a higher percentage of lime (about three times the iron) the clay product will burn buff. If the high percentage of lime is due to lumps of lime carbonate, the brick on burning will crack and warp. Very high percentages of lime are apt to ruin the clay. It is not always possible to predict the color of the burned ware from the color of the clay. Red clays will usually burn red, blue clays may burn red or buff. Dark or black clays are usually high in organic matter, and may burn red or buff. The color of clays is discussed more fully in the preceding chapter.

6. "The slaking of clays or the crumbling down in tempering is tested by dropping a lump of clay in a cup of water. Some clays slake in a very few minutes, and so are easily tempered. Shales slake usually only after a long time, and require fine grinding."

The above tests are all very simple and can be made by any person and while they may not prove absolutely the quality of the clay at the same time they may furnish a considerable amount of valuable information in regard to it and enable one to judge approximately as to its value for certain purposes.



RAYMOND BRICK DRYER

PART II

TECHNOLOGY OF THE CLAY INDUSTRY

CHAPTER VII.

MINING AND PREPARATION OF CLAY.

MINING.

In the manufacture of clay wares the first problem to be met after the deposit has been located and its extent and value determined is the question of mining and delivering the clay at the plant. There are in the clay industries a number of different methods used, and the one in use in any particular locality will be determined by the location of the deposit with reference to the plant where the clay is to be used, the stratigraphic position of the clay to be used, the character of the clay, and the position of the clay strata in the bank.

Usually it is advantageous to build the manufacturing plant as near the clay deposit as possible, and if it can be located in immediate proximity to the deposit, and have the required facilities for getting the manufactured ware to market, no other location should be considered. The conveying of the raw material is an important item in the cost of the ware and should be kept at the minimum and such a location would have that tendency. If railroad transportation is to be had for the finished product a short piece of road would better be built to the deposit as the expense of this, in the long run, will not be nearly so great as to locate the plant on the railroad and constantly bring the raw material to it. If the ware is to be drawn by teams to the main line of railroad, a difference of a few miles, after the ware is once on the wagons makes very little additional cost. The handling of the ware is the expensive part of this operation, and short hauls require as much of this as long ones and the more the ware is handled the more the loss from breakage.

Sometimes conditions are such that it is not possible to locate the plant in immediate proximity to the clay deposit. It may in

some cases even be necessary to locate it above the deposit. This may be advisable if by so doing the plant is kept on the same level with the track over which the manufactured products are to be shipped. In a case of this kind it is a question of either elevating the raw clay or the manufactured product to a level where shipment is possible. If the plant is placed on the same level as the clay, and railroad tracks can only come in above it, then it becomes necessary to elevate the ware in order to load and ship it, and this causes a large amount of handling and hence, makes it expensive. It is often advantageous to locate the plant below the deposit to be used. In a case of this kind the clay may be brought to the plant largely by the force of gravity, and in this way a considerable saving in cost of the product of the plant may be made. This same principle should be taken advantage of as far as possible all through the plant, and in fact throughout the entire process from the time the clay is loosened in the bank until the finished ware is on the cars and ready for the market. The question of water supply, drainage, fuel and things of this kind are also of importance for the plant and should all be considered together.

The methods to be used in the exploitation of any given clay deposit are determined by a number of things such as whether they are found covered with a considerable thickness of other material, whether they occur in a loose, uncompacted state, or whether they are found in flat deposits, or steeply inclined. Clay deposits may be worked by surface digging, quarrying, or by mining and the one of these methods that should be used in any particular case will depend upon the condition of the deposit.

Surface Digging.—Many clays and especially those that occur on the surface in a loose uncompacted state are worked by means of surface pits. This surface digging may be carried on in a number of different ways. In many yards, especially the smaller ones, shovels and wheelbarrows are used. This is the slowest method in use and hence the most expensive and is only applicable in the case of small plants and where a high price may be obtained for the finished ware. It would not be possible

either to use this method where the clay has to be transported any great distance to the plant. Another method that may be used in working this class of deposits is by means of the plow and scraper. By this method the clay is first loosened by means of a plow, after which it is taken up by a scraper and may be transported for some distance to the plant in this way. Different kinds of scrapers are in use in different places, but if the clay is to be hauled any distance the wheel scraper is the best suited to this purpose. This method is much more economical than the first and may be carried on much more extensively. In many yards one horse carts are used for transporting the clay from the bank to the plant.

In the case of the very large plants where a large amount of clay is to be handled, steam shovels are used. These are the most economical for the handling of large amounts of clay. They are capable of excavating material that is quite solid and compact and may be used in soft shales as well as in clays. These steam shovels have one disadvantage in that they mix the differet grades of clay that may occur at different horizons in the deposit. In the manufacture of many of the products made from the ordinary grades of clays this is no detriment, and in some cases may even be an advantage in that it makes the clay more uniform. The steam shovel may be used in a pit where the face is from fifteen to twenty feet high. The first cost of these steam shovels prevents their use except in cases where a very large amount of clay is to be handled.

The greater part of the clays used is in such a condition that no greater force is necessary to loosen them up than that brought to bear with the plow, shovel, or scraper. In some of the older deposits, however, they have been under conditions which have made them hard and compact and it is necessary to use other means for breaking them, and in some cases powder is used and they are blasted. This is especially true of flint clays and shales. Many shales have to be broken by this means before they can be handled at all. This may also be necessary in the case of very tough clays.

This method of working by means of surface pits is the one

used at a large number of the clay working plants in Washington. Where the clay has a layer of material over it that cannot be used in the manufacture of brick or tile it must be removed, and if the amount of this material is large it may be so expensive to remove, that it will not be possible to work the clay at a profit. Various methods may be used for the removal of this material depending somewhat on the local conditions. In some cases it is removed by means of teams and scrapers, in others by means of wheelbarrows, and in some cases it may be removed by means of water. In some yards this material is of such a nature that it may be mixed with the clay and used, and in this case the expense of removal is saved.

When the clay occurs along a stream, the deposits may be worked by excavating along the bank and working the clay back from the stream. The floor of the pit should be above the surface of the water in the stream, and should be inclined slightly away from the direction of working, so that the water will drain out and in this way avoid the expense of pumping.

Hillside Quarries.—Where the deposit to be worked has become more compact and hard, and considerable force is needed to loosen the material, somewhat different methods are used. The shales, which furnish a considerable amount of the raw material used in the clay industry, have been subjected to conditions which have caused them to become stony in hardness, and to this class of material especial methods, similar to those used in the quarrying of stone, are applied.

These deposits of shale are often exposed along hillsides and are worked along the exposures. When the deposit is first worked, the material on the surface, on account of having been weathered more or less may be in a condition such that it may be removed by means of a pick and shovel. When depth is obtained, however, they usually become hard enough so that blasting is more economical.

The materials over the shales, if not of such a character as to be used with the shale, must be removed. If it consists of clay or weathered shale, and does not contain gravel and

boulders it may probably be broken down and mixed with the shale and used.

The height of the face that may be worked economically will vary with the character of the material. It should not, however, be so high that the material cannot be loosened from top to bottom by the ordinary sized charge of powder. The amount of material loosened at a single blast will depend very largely on the character of the material, as well as upon the kind of explosive used. Both black blasting powder and dynamite are used for loosening the material. This loosened material is broken up by means of pick and sledge, the larger masses of foreign substances such as boulders, gravel, masses of limonite, pyrite, and nodules of lime may be removed and thrown to one side out of the way. The broken shale or clay is then loaded and hauled to the plant. If the clay or shale, after being broken down from the bank, be left exposed to the action of the atmospheric agencies for a considerable length of time, it may in many cases at least be materially improved.

The efflorescences which appear on some clay wares are due to the soluble salts which the clay contains, and if these clays are thoroughly weathered these salts would be removed. Clays which contain a considerable amount of ferrous iron would be rendered less difficult to burn by being thoroughly weathered as the iron would be changed to the ferric condition. To carry on this weathering process in actual practice would require that large masses of the clay be broken down and left exposed to the action of the frost, changes of temperature, and rains for considerable periods of time. The length of time would vary in different localities and with different clays and shales. They should in each case remain long enough to become well disintegrated and leached of soluble salts. In some cases the clay is taken from the pit or quarry and piled under sheds where it is weathered before being used. In this case the water is applied as needed, from time to time, and the clay thoroughly soaked, and in this way the process is accelerated and the desired results obtained sooner than when nature is depended upon to supply the water in the form of rain. Shales and clays are, as a general

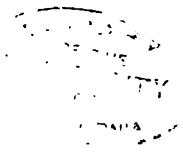
thing, rendered more uniform in texture and are more easily crushed and tempered after having been weathered than they are before, and hence a saving of power would be made on account of this.

Where the material is to be left in the quarry to weather, it is necessary to work a large face so that a large amount of material may be broken down and left exposed. In many places in the fall of the year when the dull season approaches, a large amount of material is blasted down and left exposed to the atmospheric agencies during the winter, and in the spring it is in good condition to work. In some places clays and shales are spread out in a layer only a foot or so thick where they may be occasionally stirred by means of a cultivator of some kind.

Drift Mines.—The above methods of working clay deposits are applicable only in cases where the amount of material covering the clay or shale which has to be removed is not large. In the case of ordinary clays, if this becomes large, new openings will be made or the deposit abandoned entirely. In case the clay is very desirable, however, and cannot be found on the surface, it becomes necessary to work the deposit by means of stopes, drifts, and shafts. In Washington this method is used in a few places only. This is the most expensive method of working a clay deposit on account of the larger and more expensive equipment needed.

In opening up and working clay deposits by this method the same principles are employed that would be used in the mining of coal. The mines must be carefully timbered and this is a more difficult job in the case of the clays. In some mines the clay and coal are worked together. The clay, when exposed in the mine to the action of the air and water, has a tendency to soften and the weight of the overlying material may cause it to spread out and fill the workings. By this method the question of ventilation becomes an important one and has to be provided for by shafts, and in some cases, fans to cause circulation. In many clay mines water is a source of considerable trouble and provision must be made for taking care of this, and if the workings cannot be arranged so this drains out, provision would have to be made

S. Shedd, Photo BRICK YARD OF A. T. DISHMAN, SPOKANE



for pumping. The amount of clay mined per man by this method will usually be less than by the other methods. All of these, along with several other things, add to the cost of the finished product, and hence this method can be used only for the higher grades of clay.

Shafts.—This method of working clay deposits is used the least of any. It consists in sinking a shaft down through the material which covers the clay until this is reached and then by working out from this. This method is used sometimes in the case of kaolins or china clays, and could be used profitably only where such clays even could not be obtained in any other way.

HAULAGE.

The transporting of the raw clay to the plant may be accomplished in a number of different ways, and the one to be used will be determined by a number of different things, such as amount of clay to be transported, location of the plant as regards the deposit, power to be used, etc.

In case the distance is not great and the slope very little the clay may be transported from the pit to the works by means of wheelbarows. If large amounts of clay are used and the distance is more than a few rods other methods must be used. In some yards one-horse carts are used. In this case the clay is usually loaded onto the carts by hand and may be hauled and dumped near the preparing machinery. This method, like the first, is best adapted to small yards, where small amounts of clay are used and where the clay is to be moved only short distances. In yards where the material being used is soft enough so that it can be worked with the shovel or the plow, wheeled scrapers may be used for transporting the clays. By this method the clay, after being loosened by means of a plow, is scraped up at the point where the deposit is to be worked, and hauled on the scraper to the plant. This method has an advantage in handling the clay but once in getting it to the plant. If the distance that the clay is to be moved is not too great, large quanitties may be moved by this means quite economically. This method, however, is applicable to only cer-

tain kinds of deposits and under certain conditions. It can be used only where the clay is taken from a shallow deposit, and cannot be used to advantage where the deposit is thick and worked as a bank.

In some cases where the clay is to be transported for considerable distances and not a large amount is to be used it may be hauled to the plant in wagons. This method of transportation is not used except for the better grades, such as kaolins, high grade fire clay and material of this kind. Clays are sometimes shipped by rail to distant points to be mixed with a clay which occurs near the plant, and in some cases all the material to be used at a given plant may be supplied in this way. This would probably be applicable to only the better grades of clay. In Washington this is done at one place where sewer pipe and terra cotta are the main products.

The most common method for transporting the clay to the larger plants is by means of tracks over which small cars are run. In some cases these tracks are made with wooden rails, while in others of a more permanent character they are made of iron. This is the most economical method of any where large amounts of clay are to be moved and especially where the slope to or from the plant is steep. Where the plant for working the clay is situated below the deposit the clay may be hauled largely by gravity, and in some instances the loaded cars as they descend may be made to haul the empty ones back up to the bank. In most plants a certain amount of clay is kept on hand at the works as a reserve supply so that in case of any delay or accident to the hoisting apparatus the plant would not have to stop. In some cases a considerable amount is always kept on hand under sheds and in case of stormy weather this will be used instead of bringing it from the bank. The shed in which to store the clay should be located near the machinery so the extra expense for handling may be as small as possible.

In most cases the car tracks are so arranged that the clay is delivered above the grinding machinery and dumped onto a platform from which it may be fed directly to the machinery, or dumped into bins and from these supplied to the crushing

machinery. In all cases it is desirable that the bins or platform be situated above the grinding machinery so that gravity may be used as far as possible in handling the clay.

Whatever the system of transportation made use of, one of the very essential things to be kept in mind when locating the plant is to so arrange things, if possible, that the raw clay may be delivered from the cars above the preparing machinery. By such an arrangement labor is saved in the handling of the clay, and the finished product cheapened. The ideal condition, of course, is to have the machinery located below the level of the pit. This, however, is not possible in all cases, and the clay must be elevated somewhat. Even where horses and carts or wheelbarrows are used to transport the clay it is generally possible and more economical in the end to deliver the clay above the machinery of the plant.

PREPARATION OF THE RAW MATERIAL.

Very little clay or clay material is in a condition when it comes from the bank to be formed directly into wares. In some cases it is a hard material such as shale and must be ground. Clay banks are seldom uniform throughout as regards the character of the material, and in order to give a uniform product they require a very careful mixing. This is a very important point in the manufacture of almost all clay wares and the more the clay is worked in the process of manufacture the better will this be accomplished. The more uniform the composition of the clay the better the results obtained in the burning and the more uniform the product. It is not enough that a certain amount of clay having a certain composition be present, but it must be uniformly distributed throughout the mass. The grinding gives the clay a more uniform texture, which is also an advantage. The clay is, in most cases, thoroughly mixed with water before being formed into wares of different kinds. The above results, that is, the reducing of the clay to a uniform texture and to such a texture as experience has shown, will give the best results for any particular class of wares and the thoroughly mixing of

the different constituents so as to give a homogeneous mass, may be accomplished by either the dry or the wet method.

DRY METHODS OF PREPARATION.

Crushers.—The clay as it comes to the plant consists of coarse and fine material, and small and large lumps. The first step then, in reducing this to the condition desired, is to break up the larger masses so that the clay will have more nearly uniform particles. This is more especially true in the case of the shales and harder clays such as the flint clays. There are a number of different makes of crushers used for this purpose, and the one to be used in any particular case will depend somewhat on the character of the material to be crushed. Jaw crushers are often used, especially for hard shales and flint clays. These can be used in the clay industry only when the material to be crushed is very dry or a very brittle substance. This is due to the very great tendency that clay has for packing, even when apparently dry when pressure is applied, and in this way it may clog the machine.

Rolls.—Rolls may be employed in the clay working industry for breaking up shales, clay, and pebbles. When the material is perfectly dry these may be used advantageously and give good results, but where the clay is damp the tendency is to simply flatten out the lumps. In damp clays they are sometimes used, however, mainly to remove the pebbles and masses of hard materials that are so large that they will not pass through between the rolls and to knead the clay. For this purpose special patterns are used so arranged that the material to be gotten rid of works along the rolls, to one end where it is discharged.

There are many different types of rolls which are used in working clay, and before a machine can be selected that is sure to give the best results on any particular clay a thorough knowledge should be had of the clay.

Dry Pans.—Where crushers are used the material may, in some cases at least, be completely pulverized while in other cases it is conveyed to a dry pan and more finely pulverized. In

many cases the material is taken direct from the bank to the dry pan and ground without the preliminary use of crushers or disintegrators. Dry pans are used more extensively in the clay working industry, for the pulverizing of clays and shales, than any other kind of machines. This is due largely to the fact that they may be used to advantage on so many different kinds of material. It will pulverize any hard material, as worn out fire brick to be used as grog, flint clays, and shales as well as the softer raw clays.

This machine consists essentially of a revolving metal pan, over the bottom of which roll two heavy wheels or mullers. The pans vary in size and range from five to nine feet in diameter with a rim of steel about fourteen inches high. The central part of the floor of the pans is solid and over this part roll the mullers, the outer part of the floor of the pans is perforated so as to form a screen and after the rolls pass over the clay it is carried out over this part of the floor by centrifugal force, and small particles pass through the screens to a receptacle beneath, which concentrates and delivers it at the foot of an elevator which carries it to the screens. The clay that has failed to pass through the screens is thrown back in front of the mullers by means of scrapers set in certain positions for this purpose. The size of the perforations in the screens varies, depending on the fineness of the material desired, but they average about one-eighth of an inch in diameter. Screens with either larger or smaller openings may be used, however.

The power required to drive one of these dry pans will vary with the character of the material to be ground and the degree of fineness to be obtained. It is not considered economical but so far, no other machine that does the same work and that may be operated more cheaply has been found to take its place.

Ball Mills.—These are used to a considerable extent in some places for pulverizing clays to be used in the manufacture of the finer grades of ware where very fine grinding and intimate mixing of the ingredients is required.

CONVEYORS.

After clay has been pulverized by any of the above methods it usually is taken to screens and storage bins. This is accomplished most readily and economically by means of conveyors. These conveyors vary somewhat in the manner of construction on account of the varying conditions under which they are to be used. In case the clay is not to be elevated to a much higher level the conveyor may be a belt or rubber apron with flanges on the sides to prevent the clay from falling off. These vary in width from about eighteen inches to thirty inches. When the inclination becomes greater cross-pieces may be added to the belt, and when the incline becomes very steep or vertical metal buckets are used on the belts. In this type there is a series of iron or steel buckets of a given size fastened to a belt or sprocket chain at given intervals. These buckets take up the clay below, and as they turn over the pulley at the top discharge into a spout which leads to a screen or to a bin.

SCREENS.

In very few if any of the processes described above for the pulverizing of dry clays are the particles reduced to such a condition that they are uniform enough in size so that they do not need a further grading. In the dry pan the screen becomes worn and lets through coarse particles. In the case of the crushers of different kinds also different sized particles pass through them. This grading is accomplished by means of screens and all of the material in which the particles are larger than a given size is returned to be reground. The screens used in the clay industry are made from either wire netting or perforated metal, the latter usually being considered the better on account of having a smoother surface and wearing longer. Perforated screens are also more easy to clean and keep clean. Screens are made with various sized openings or having different meshes depending on the size of the particles that are to pass through them. The screens for clays are made in three general types: inclined stationary, inclined vibrating, and rotary.

TEMPERING.

The methods of crushing clay so far described are used mainly in connection with dry clays and shale and have for their object the reduction of the clay particles to a smaller and more uniform size. In the working of clay and the manufacture of clay wares it becomes necessary to develop the plasticity of the clay by mixing it with water and bringing the whole mass to a uniform condition. This operation is known as tempering and may be accomplished in various ways and by means of various appliances. In some cases the grinding and tempering may be accomplished at one operation, while in others it is first ground and tempered afterwards.

Wet Pan.—The wet pan may be used both for pulverizing and tempering the clay as it comes from the bank or it may be used only for the tempering of the clay after it has been ground in some other kind of pulverizer. In construction it is very similar to the dry pan except that the bottom of the pan is solid instead of perforated.

The clay may be shoveled into the pans or it may be delivered from above them by means of a spout, the proper amount of water is added to bring it to the proper consistency and it is thoroughly ground and mixed. By means of a long-handled shovel, mounted on a pivot near the pan, the tempered clay is removed while the machine is still in motion, after which another charge is added and the operation repeated. While the wet pans may grind and temper the clay at one operation its work is intermittent as the tempered clay must be removed before more may be added. On account of this fact it has a smaller capacity than a dry pan of the same size, but at the same time it performs two operations. The wet pan is used more especially in tempering clay which is to be used for the manufacture of pottery, sewer pipe, and terra cotta, and is but little used in brick and tile plants. If used on clays direct from the bank there is always a chance that there may be small lumps that may not be pulverized so that it is always safer to grind the clay by some one of the methods given above before tempering it.

Pug Mill.—The pug mill may be used on certain kinds of clays for mixing and tempering without their having been previously pulverized. Its principal and by far its most important use is in mixing and tempering ground clays. It is used extensively in mixing and tempering clay for the manufacture of paving brick, common brick and drain tile.

The pug mill consists of a semi-cylindrical trough which is usually made of steel, but may be made of wood, and varies in length from three to sixteen feet with about six or eight feet as an average.

Through this trough extends a revolving shaft on which are mounted a series of projecting steel knives. These knives are set spirally around this shaft, and each so placed that its side makes an angle with its plane of revolution. By this arrangement the clay is gradually worked to one end of the trough where the rate of discharge is regulated by means of a movable gate. The rate at which the clay will be carried forward will depend on the angle at which the knives are set and the rate of revolution.

These pug mills are made with the trough either open on top or they may be closed. In the case of the closed trough the clay is worked under pressure, and the knives are much more effective in pulverizing and mixing the clay. They are usually made horizontal, and may either be made as a part of the brick machine or separate from it. The mill, if separate from the press, is usually placed a little above it so that the clay as it is discharged from the pug mill will drop down into the hopper of the machine.

The clay is fed into the hopper of the pug mill from the bin and water enough added to bring it to the proper constituency for molding. The amount of water has to be carefully regulated by an experienced man. This is a very important point as too little water may cause the bar of clay, as it comes from the machine, to be broken or cracked, or if too much water should be added the brick would be soft and easily injured in handling, they will take longer to dry and will have a larger amount of shrinkage than if the proper amount of water is added. The

S. Shedd, Photo PLANT OF THE BERGMAN CLAY MANUFACTURING COMPANY, CHESTER

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capacity of these mills will vary a great deal depending somewhat upon the character of the clay. According to Grimsley* a nine-foot mill will temper, in average clay, enough in ten hours to make from 30,000 to 45,000 brick.

For the tempering of clays and the preparation of wet clay the wet pan and the pug mill aready described constitute the most modern methods.

*West Va. Geol. Survey, Vol. III, p. 114.

CHAPTER VIII.

THE FORMATION OF CLAY WARES.

In this chapter the various methods in use for forming, or the manufacture of clay wares will be discussed giving those only, however, that are applicable to the kind of wares manufactured in Washington at the present time. The following outline taken from the report on the Iowa* clays shows the different methods in use for the manufacture of the different kinds of wares:

Manufacture of brick.....	Wet...	Soft mud....	Hand. Machine
		Stiff mud....	Machine.
	Dry....	Machine.	
Manufacture of drain tile and hollow block.....	Wet...	Stiff mud....	Machine.
Manufacture of sewer pipe....	Wet...	Stiff mud....	Machine.
Manufacture of pottery.	Wet...	Hand. Machine.	

MANUFACTURE OF BRICK.

Brick are made in two essentially different ways as the wet method in which the clay is mixed with water and thoroughly tempered or by the dry process, where the finely ground clay is pressed in a dry condition. As shown in the outline above there are modifications of these.

Soft Mud.—The soft mud process of making brick is the one that was first used and is still used in many places through-

*Beyer and Williams, Iowa Geol. Survey, Vol. XIV, p. 185.

out the country. Originally the molding of the brick by this process of manufacture was done by hand but at present many soft mud brick are machine molded. After the clay had been tempered, usually in the wooden armed pug mill it was forced into the mold by hand. The man who does the molding takes a lump of the tempered clay sufficient to make a brick, and fills the mold with it. This is done by bringing it down with considerable force so as to fill out all parts of the mold. The molds are sanded to prevent the brick from sticking. Molds usually have from four to six compartments. When a compartment has been filled the top is smoothed off by cutting off the clay that projects above the edges of the mold with a wire or a thin blade to which handles are attached. The mold is then taken to the yard and emptied and the brick left to dry. Expert molders can make from 3,000 to 5,000 brick per day and are usually paid by the 1,000 brick.

In the manufacture of some kinds of ware, as good if not better results are obtained by hand than by machine molding. In the case of fire brick for instance it is essential that they should have a uniform structure, free from lamination, as well as an open porous one, and all of these are insured by hand molding, and on account of this many refractory brick are still molded by this process. Hand molded brick do not have the smooth surface of machine made brick, and on account of not having been subjected to any pressure to speak of in their manufacture, are not used very much for front walls of buildings. They are well adapted, however, for many of the purposes for which brick are used, and especially if the question of appearance is not of any very great importance. This method is especially well adapted to small yards that are operated periodically only, as the machinery and equipment of the yard is not expensive and the method is a cheap one.

Special types of machines are also made for making soft mud bricks. These are made in such a way that they work the soft clay into molds similar to those used in molding brick by hand. These machines are made after a number of different plans, some being horizontal while others are vertical. They

consist essentially of some sort of pugging mill, in one end of which there is some arrangement for forcing the clay into the press box, and press plates or plungers for pressing the clay into the molds.

The sanding of the molds is a very important point in the manufacture of brick by the soft mud process. This may be done either by hand or by machines made for that purpose. In most yards this is done by hand. Fine sharp sand is used for this purpose. The molds are first wet and then the sand is put in them and the molds shaken so that the sand will be brought in contact with the whole of the inner surface of the mold. The excess sand, that is the sand which does not adhere to the mold, is dumped out. Under favorable conditions soft mud machines may produce as high as 35,000 to 40,000 brick in a day of ten hours.

The soft mud process may be used on a greater range of clays as regards their different properties than any other and it also has the advantage of producing bricks which have a very homogeneous structure. The bricks, however, have a more open or porous texture than those that have been subjected to greater pressure in the manufacture.

Stiff Mud.—The stiff mud process differs from the preceding in that less water is added to the clay in bringing it to the condition for molding. In this case just enough water must be added to produce a stiff, plastic mass, but it does not flow under slight pressure as it does in the soft mud process. The clay must be of such consistency that when it is forced through a die it will conform to the shape of the die and such also that the bar formed will be strong enough to retain its form even when subjected to considerable strain.

There are two principal types of stiff mud machines that are being used at the present time. These are the horizontal and the upright. These are both what are known as the auger machines and consist essentially of a short pugging machine, the knives being attached to a horizontal shaft one end of which is an auger. The clay usually comes to the auger machine from some machine where it has been thoroughly

tempered and made plastic. Brick machines are made, however, where the pug mill for tempering the clay is a part of the machine and is combined with it. Attached to the end of the brick machine which contains the auger is the die. The clay is supplied through a hopper at the other end of the machine and the revolving knives carry it forward to the auger, and then this forces it on through the die and out of the machine as a compact bar of clay. The size of this die and hence the bar of clay will vary, depending on whether the brick are to be end or side cut. If end cut the bar of clay will have the width and thickness of a brick, but if side cut the bar will have the width and length of the brick.

The auger machine has a tendency to produce a laminated structure in the clay, and the bar of clay as it issues from the machine is seldom homogeneous throughout. Very plastic clays are more apt to have this laminated structure developed in them than those that are not so plastic. In passing through the die on account of friction on the outer part of the bar of clay with the die the outer part of the bar will move slower than the central part and this may exaggerate the already existing defects or produce new ones. Friction produced by the clay in passing through the die may cause the edges to be rough or broken. These difficulties have been overcome to a considerable extent by means of dies and augers of special design and the friction in the die may be overcome more or less by means of steam heating and oil lubricating. If the clay is properly handled the bar of clay should have smooth, sharp edges and square corners.

The bar of clay, when it issues from the machine, runs onto a moving belt which carries it to the cutting table. In some machines dies are arranged so that two bars of clay, each having the width and thickness of a brick, issue simultaneously. The improved type of machine is often provided with a sand box so arranged that the bar of clay is sanded as it issues from the die. The principal use of the sand is to prevent the brick from sticking to the conveyor belt and to prevent them from sticking together when placed on top of each other on the car or in the

dry room. It is also claimed that it is beneficial in giving good color to the brick in burning. Very plastic clays and very short, sandy ones are not well adapted for use in an auger machine.

Cutting Table.—Cutting arrangements of various types are manufactured and in use at different plants throughout the country. These cutting devices are so arranged as to make either side or end cut brick, and are either automatic or are operated by hand. The cutting is done by fine wires which are tightly drawn from the projecting parts of a metal frame.

Repressing.—The repressing of bricks made by the stiff mud process and used for certain purposes has come into quite general use so that nearly all paving and some building brick, especially those that are to be used as facing brick, are repressed. Soft mud brick may also be repressed, but it is not as applicable to this class of brick as to the stiff mud. Soft mud brick would have to be partially dried before being placed in the repress. The process consists in subjecting the previously molded brick to high pressure. The brick may be taken directly from the cutting table and placed in the dry press or they may be partially dried first.

The repressing of stiff mud brick serves a number of purposes. The repressed brick are smoother, have sharper edges and corners, and truer angles. It enables the manufacturer to stamp any design on either or both sides by having these cut in the dies as in paving blocks and sidewalk brick. The repressing makes the brick denser and stronger.

Paving brick which have been repressed are generally considered of better quality than those that have not been repressed. It gives a smoother and more compact surface, and hence would lower the absorption. It is also claimed that any lamination that may have been produced by the auger in the brick machine will be removed.

There is a difference of opinion, however, as to what effect the repressing of paving brick has, some even claiming that they are injured. It would seem that the result will depend largely on the character of the material from which the brick was made and the conditions under which the repressing is done.

In many cases it has been found that repressing is a detriment to the wearing qualities of paving brick. The repressing may produce an entirely new structure in the brick. This will depend on whether the clay particles are free to move when the pressure is applied in the repress. In order for the particles to do this the brick must fit loosely in the mold of the repress.

Dry Press.—The dry press method for molding brick is being used quite extensively at present for the manufacture of brick where very smooth surfaces, true outline, and fine texture is desired. This process has taken the place very largely of the repress method in the manufacture of the better grades of building brick such as those that are used for the fronts of buildings.

Some of the advantages claimed for this process are that in one operation it produces a brick with sharp edges and smooth faces. As the clay is dry or practically so when molded there is no water to be driven off and the operation of drying is done away with and the brick may be taken directly from the press to the kilns.

In the preparation of the clay for the manufacture of brick by the dry press method it is usually stored in sheds for some time before being used. The object of storing under sheds is to allow the moisture to thoroughly permeate the whole of the mass of the clay. This causes it to become more plastic and to make it all of the same consistency. Clays to work well in the dry press should have moisture enough in them so that when pressed in the hand it will just retain the form given it. The amount of water that is necessary to produce this result will vary a great deal with the different kinds of clays, and ranges from about 5 to as high as 15 per cent.

After the clay has been stored long enough to produce the desired result, it is broken up by means of a disintegrator or dry pan, screened and carried to a bin above the press. The dry press machine is used for making various shapes and designs by inserting different shaped molds in the machine, and the faces or edges may be modified in this way. Hand power

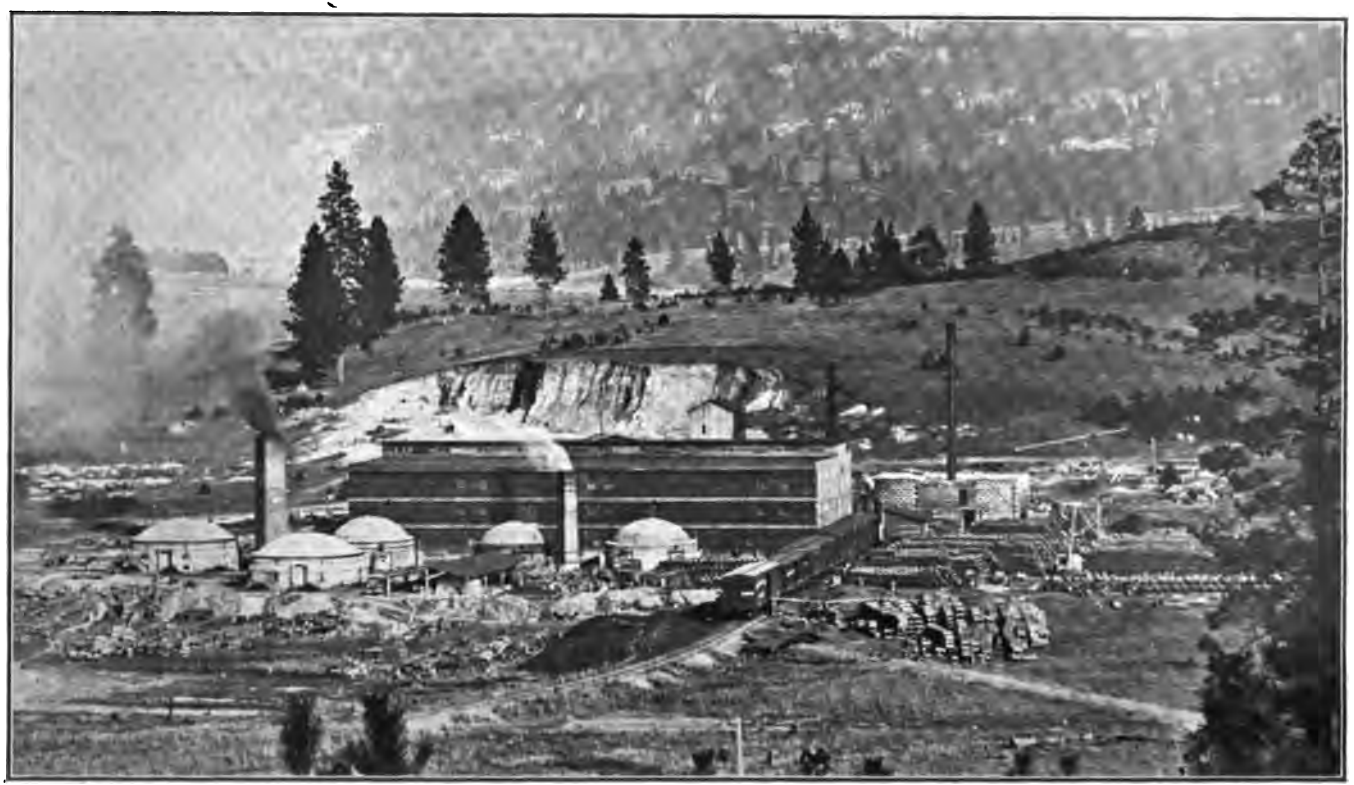
dry presses operated by means of a screw and lever are used more especially for these ornamental forms on account of the fact that the operation is under more perfect control and as they contain a larger number of angles and corners are more apt to adhere and in this way have the edges or corners broken. Dry presses are made having various capacities depending on the number of molds.

The dry press method is one of the cheapest methods for the manufacture of brick and especially those of the better grades. The stiff mud process is the most rapid method in use at present for the manufacture of ordinary building brick and for this kind it is probably the cheapest method also.

MANUFACTURE OF DRAIN TILE, HOLLOW BRICK, AND BLOCKS.

In the manufacture of drain tile, hollow brick, and blocks the clays are given the same preparation as for auger machines when brick are being made. They should be tempered to the same plasticity and are put through the same machine, the only difference being that a different die is used. The die gives the shape to the bar of clay and is so formed, in this case, that it will give a hollow column of clay in place of the solid bar used for brick. Many common clays are used for the manufacture of tile. In the case of hollow brick and blocks of various kinds the clay must be of such a character that it will flow through the die and not tear on the edges and corners and on account of this should be more plastic than some of the clays used for tile. The hollow brick and blocks of various kinds are also subjected to considerable pressure when placed in buildings, and hence the clay should be one that will burn to a dense strong body. The following are some of the advantages claimed for hollow blocks*: "May be economically produced, have a great enough strength to insure a large factor of safety in any ordinary building, are manufactured by using from one-third to one-half of the amount of clay used in the solid ware to occupy the same space, are lighter and hence more cheaply transported,

*Beyer and Williams, Iowa Geol. Survey, Vol. XIV, p. 214.



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and walls built of them are fully as protective against dampness and temperature as solid brick walls."

MANUFACTURE OF SEWER-PIPE.

Sewer-pipes are made in a special type of press made for this purpose. The machine consists of two cylinders placed one above the other. These cylinders are connected with each other by means of a continuous piston. The piston is propelled by the admission of steam into the steam cylinder or upper one and this slowly pushes down the clay plunger and forces the clay out through the die as a stiff mud cylinder which is cut into the desired lengths. This cutting may be done by hand with a fine wire or may be done automatically by a special device attached to the machine. The operation is intermittent as the piston rises after the required length of pipe has been delivered or its length of stroke has been reached and more clay is needed. The clay must be prepared and tempered before being put into the press.

MANUFACTURE OF POTTERY.

Under this head will be described the methods of manufacture of the commoner grades of pottery only, as jugs, jars, flower pots, and ware of this class. For the manufacture of these kinds of ware the clay may be taken from the bank and tempered without preliminary treatment. After the clay has been tempered it is put through a process known as wedging. This consists in repeatedly cutting, with a fine wire, a piece of clay of convenient size to be handled, then bringing the two pieces forcibly together, cutting again and so on until all the air is forced out of the clay and it has the required firmness and structure. It is claimed that the wedging produces a grain that can be obtained in no other way.

A lump of this wedged clay of sufficient size to just make the desired piece of ware is then taken and, if it is to be turned or the ware formed by hand, placed on the throwing-wheel. After the piece of clay is placed on the rotating plate it is shaped with the hands and gradually given its required size and outline

after which it is detached from the wheel by passing a fine wire underneath it and the article set aside to dry. Only certain kinds of ware, such as those having a circular cross-section, and also those in which the walls have a fair thickness can be made in this way.

The potters' jolly wheel, which is being used quite extensively at present, consists of a horizontally rotating disc on which is a hollow metal head in which plaster of Paris molds are placed. These molds have the required size and outline of the ware to be molded. The amount of clay required to produce the given piece of ware is placed in the mold and roughly shaped with the hands while the mold is being rotated. After the clay has been spread out over the inner side of the mold and given its shape roughly the operation is completed by means of a pull down arm on which is an arrangement for shaping the interior of the ware. By means of this arm with its attachment the clay is evenly distributed over the mold and the interior of the ware smoothed. The plaster of Paris molds are made quite heavy so that when set into the head of the machine they will rotate with it. The jolly is used in the manufacture of large flower pots, jars, cups, and jugs.

Especially designed machines are used for the manufacture of the smaller sized flower pots. Sizes ranging from about two to as much as six or seven inches in diameter are made on these machines by simply changing the molds.

STONEWARE GLAZING.

Stoneware articles are usually covered with some kind of glaze. These glazes are substances which, during the burning of the ware, fuse and form a glass which attaches permanently to the surface of the ware in a thin layer and serves either for decoration or to protect the surface of the ware. Glazes to to be satisfactory must have a uniform composition, run evenly when melted, fuse at rather low temperatures, and not craze or shiver when the ware comes from the kiln. In the ordinary grades of stoneware the burning is not carried to the point of vitrification and hence the body of the ware is porous and in

order to make these wares suitable for holding liquids they must be glazed.

There are three kinds of glazes that are sometimes made use of for this kind of ware as follows: Slip, salt, and Bristol glazes.

Slip Glaze.—The slip glaze is a natural clay used for glazing. The clay is mixed to a creamy consistency and applied to the part of the ware to be glazed before burning so that burning and glazing are both accomplished at one operation. The slip is applied either by dipping the ware into the slip or it may be applied with a brush. For interior glazing a pump may be used to force the slip into the inverted ware.

Slip clays are found at a number of different localities in the United States, but the one that is most used is from Albany, N. Y., and is known as the Albany slip. The amount of slip used by a large factory, even, is not very great so that the demand for this kind of clay is limited. The main difference in these slip clays from the different localities is in the relative amount of the different fluxes. In some cases artificial fluxes have been mixed with the clay so as to cause it to fuse at a lower temperature.

Salt Glaze.—Salt glazing is not practiced at the present time to any very great extent in the manufacture of stoneware, but is the form of glaze that is employed in the manufacture of sewer pipe. It represents the simplest form of glazing ware and is applied by simply putting common salt into the fire when the temperature of the kiln has reached the maximum used in burning the ware. The ware to be salt glazed is placed in the kiln unprotected from the fire and when the proper temperature is reached and the burning of the ware about completed, the salt is shoveled into the fire boxes a shovel full or two at a time at regular intervals so that the addition of the salt may be continued for several hours. The intense heat causes the salt to vaporize and the vapors passing through the kiln come in contact with the ware and unite with it to form the glaze. Ware to be salt glazed must be made from clay that fuses only at temperatures above the point at which salt vaporizes and if it

will stand a temperature several cones above this the greater the probability of securing a good glaze.

Many clays take good salt glazes while others will not take a salt glaze at all. From experiments carried on by Mr. L. E. Barringer* the following conclusions were reached:

1. "A clay may be either too aluminous or to siliceous to be successfully salt glazed.

2. "Clays containing alumina and silica between the molecular ratio of 1.00 alumina to 4.6 of silica; 1.00 alumina to 12.5 of silica are capable of receiving a salt glaze if the process is properly carried out. If these limits are exceeded the material is not suited for salt glaze ware.

3. "While it is possible to salt glaze clays containing alumina and silica in the above ratios, the requirements of the process of making stiff mud goods would not permit the use of such siliceous clays as those with an alumina silica ration of 1 to 9 or 1 to 10. That is, the practical values of a clay, as to plasticity, strength, etc., will draw narrower limits than those found in the above tests.

4. "As regards brightness, smoothness, and finish of the salt glaze it makes but little difference whether the free silica in the clay is fine or coarse.

5. "As regards colors, the finer the sand the lighter the color of the glaze."

It has usually been considered that efflorescent salts in a clay acted as a hindrance to salt glazing but Barringer found that as much at 3 per cent. may be present without seriously interfering with the salt glazing.

Bristol Glazes.—The Bristol glazes are artificial glazes that are produced by mixing together certain fluxes with kaolin and flint as a basis. These glazes are of various colors due to the addition of different artificial coloring materials. This glaze is being used more than any other at present in the manufacture of stoneware.

*Trans. Am. Cir. Soc., Vol. IV, p. 211.

CHAPTER IX.

DRYING AND BURNING OF CLAY WARES.

DRYING.

In most cases the freshly molded clay ware contains a considerable amount of water which has to be gotten rid of before the clay can be placed in the kiln and burned without danger of the ware being injured by it. This water has been obtained from three different sources. There is always a certain amount of water which is combined chemically with the different elements in the clay and which cannot be gotten rid of except at high temperatures. Clays absorb from the air and hold hydroscopic moisture which may be gotten rid of at a temperature a little above 100 deg. C. Then there is the water that has been added to the clay in tempering to make it plastic. This latter is the water to be evaporated in the drying of the ware before being placed in the kiln. The amount of water required to temper the different clays so as to make them suitable for molding into the various kinds of ware varies from a minimum of from 14 to 16 per cent. to a maximum of as much as 33 to 35 per cent. In the drying of clay ware then it is the question of the evaporation of a given amount of water at the least expense under such conditions that the form and strength of the ware may be retained.

DRYING OF BRICK.

There are a number of different methods of drying the green brick which will be considered under the following heads: (1) Outside drying; (2) Drying floors; (3) Periodic or chamber driers; (4) Continuous tunnel driers.

Outside Drying.—This is the oldest and simplest method in use for drying brick and consists simply in exposing the green brick to the heat of the sun and the natural air currents. At the present this open air drying is carried on in one of two

ways as follows: By placing the brick on a level piece of ground, without any cover, exposed to the direct rays of the sun and the air or by placing them under some kind of cover so that they are protected from the direct rays of the sun.

In the first case the ware is dried by the direct rays of the sun and the circulation of the air over the upturned surface of the brick. This method of drying requires very little expense to equip the yard, and as the heat is natural heat nothing is required for fuel. The method is one, however, that depends entirely upon the conditions of the weather and hence the rate of drying will vary much on account of the difference in atmospheric conditions, and the yard can be operated for only a part of the year on account of this. The atmospheric changes may be such that many clays cannot be dried in this way without injury to the brick.

This method is used mainly in the smaller yards and in the drying of brick that have been molded by the soft mud process. In operation the brick are spread out on a hard floor in the open air. This floor may be of dirt or of brick with a thin layer of sand spread over it.

In the other method of outside drying the brick are placed on pallets and these are set on racks or cribs and the brick allowed to remain on these until they are ready to go into the kiln. These racks are made of a series of posts to which cross arms ars fastened. The pallets containing the brick are placed on these in vertical rows of about eight to twelve pallets. The pallets are protected by a shed roof which projects out over them on each side so that in case of storms the brick are protected. These racks are of any length and should be far enough apart to allow the wheelbarrows carrying the brick to pass between them.

This method has some advantages over the one described above. The capacity of the yard is increased. The open arrangement of racks allows the free circulation of the air around the brick. The brick dry slower and are not so apt to crack and warp as they are when they are subjected to the direct rays of the sun on a hot summer's day. The brick are subjected to

less handling between the machine and the kiln. Some of the disadvantages are the fact that the clay must be stiffer when worked and then there is greater expense of equipment of the yard in the building of the racks. In some cases the racks are so arranged that the roof may be opened and the brick exposed to the sun's rays after they are partly dried. This method, like the first, can be used during only a part of the year.

Drying Floors.—Sometimes brick are dried on floors which may be constructed of either brick or wood. In the case of a wooden floor the brick may be dried by currents of air, of ordinary temperature, or artificially heated, passing over them. In some cases slatted floors are used for drying brick similar to those used for sewer-pipe. Brick floors may be heated by hot air, by steam, or by means of flues beneath them.

The floor in some cases is heated by means of flues or fire boxes which are located underneath it and extend the entire length of it. At one end these flues connect with the stack or chimney to produce a draft. In the other end of the flue the fire is built and the heat and the products of combustion pass the entire length of the flue and then up the stack. The brick are set on edge or on end on this floor as in outdoor drying. The water is evaporated and passes out of the building usually through ventilators placed in the roof of the building. The temperature is very unequal on different parts of these drying floors, the end over the fire being much hotter than the end by the stack, and this causes a large amount of handling of the material. The under surfaces of the brick are raised to high temperatures and dried faster than the other parts, and hence there is a greater tendency for them to crack and warp than where they are dried evenly. This method is wasteful of heat and fuel by allowing the air, which has become somewhat heated, to escape before it has become saturated with moisture, and heat is wasted in this way. It has the advantage of not being affected seriously by weather conditions.

In some cases the top of the kiln is used as a drying floor. This, under certain conditions may be done in the case of the continuous kilns. The brick may be spread out over the top

of the kilns as they are in outdoor drying or pallet racks may be built along the top of the kilns. At one brick plant in Washington the top of the kiln is used as a drying floor on which a part of the brick are dried. This may be done to best advantage where conditions are such that the molding machinery may be placed on the same level as the top of the kiln.

Periodic or Chamber Driers.—The intermittent tunnel drier consists of one or more compartments or units with inlets and outlets for the air. The amount of air that is entering and escaping at any time can be regulated in this class of driers, and hence the temperature may be regulated. The green brick are placed on cars, either on pallets or by being stacked on each other, and run into the tunnel on steel tracks until the tunnel is filled, when the doors are closed, the heat turned on, and the draft regulated so as to produce the required conditions in the chamber. Each compartment or chamber is separate and so arranged that when one is being emptied others may be filled with brick in the process of drying and still others being filled.

In these driers the temperature is the same in all parts and may be varied as the operator sees fit so that the brick may be heated gradually until completely dried, and there is on this account not much danger from cracking and warping. Each chamber is completely filled, dried, and then emptied, and then the same operation repeated.

The air is admitted by means of small flues in the floor, which connect with a large air trough which extends the full length of the chamber underneath the floor. The moist air may escape through chimneys placed along the tunnel or through one large central chimney. The air is usually heated by means of steam pipes, placed below the floor, before being admitted to the tunnels. A three part steam coil has been found most successful, all parts of it being placed below the track. In this sort of an arrangement one part only is turned on at first and the other parts are turned on as different points in the drying process are reached and higher temperatures desired, all three parts being used in the last stage when the highest temperature is desired. There is a considerable waste of heat in this type

S. Shedd, Photo. CLAY BANK, FREEMAN

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of dryer, partly on account of the fact that the air escapes before it is completely saturated, and then in removing the dry brick the air of the tunnel is cooled down before it is filled again.

Continuous Tunnel Driers.—The continuous tunnel drier is the one generally used in all of the larger brick plants as well as in many of the smaller ones. These consist of tunnels which are usually from about eighty to one hundred and twenty feet long, five feet high, and four feet wide. Several of these tunnels are constructed side by side under one roof and may be separated by partition walls in some cases while in others they are not. Through these tunnels tracks are laid from the machine to the kiln. The tunnels are heated by means of hot air or by steam.

If soft mud brick are to be dried they are placed on pallets and these piled one above another on steel cars. Stiff mud brick are stacked on each other on the cars, the rows being placed at right angles to each other. These cars vary in capacity from those holding 300 to those which hold as many as 600 brick. The cars when loaded with green brick are pushed to the turntable in front of the tunnel and turned to the proper track and placed in the cooler end of the tunnel. The next car put in pushes the others forward gradually, reaching hotter and hotter portions of the tunnel until the discharge end is reached where the temperature is the highest and where the drying is completed. The capacity of the drier should be great enough so that the bricks may pass through slow enough so that they may be gradually heated and dried and danger from cracking and warping avoided.

There are a number of different types of these tunnel driers that are being used at present in different places, the principal difference, however, being in the manner in which they are heated. In one type the heat for the drier is supplied by a furnace and the hot air may be forced into the tunnels by means of a fan or conducted by means of pipes. The furnaces are built under the discharge end of the tunnels, and the heat is conducted along

under the tracks by means of flues. The moist air and waste gases escape by means of a stack at the entrance end of the tunnel. Air is admitted to the drying tunnels through openings on each side of the fire box, becomes heated by the furnace and rises around the brick.

A second method is to use steam heat. In this type the steam pipes are laid along the floor of each tunnel or along the sides. At the discharge end of the tunnel there is a series of radiator coils with which the steam pipes are connected. The steam in some cases is live high pressure steam while in others the exhaust steam is used and in still others arrangements are made so as to use exhaust steam when the plant is running and live steam during the balance of the twenty-four hours. This latter arrangement has proven very satisfactory and economical. One of the strongest points in favor of this method of drying bricks is the fact that a large amount of heat may be utilized that otherwise would be wasted. Steam again is easily conveyed and controlled which is a point in favor of this method of heating.

A third method for heating tunnel driers is by means of hot air. In this method the hot air may be supplied from the cooling kilns or by passing air over steam coils before it is drawn through the tunnel. In case the hot air from the cooling kilns is used it is drawn from the kilns by means of a fan and forced through the tunnels. There is a mixing chamber connected with the fan so arranged that cool air may be drawn in from the outside and mixed with gases from the kilns, and in this way cool them should they be too hot. The amount of air forced through the tunnels may be regulated by regulating the speed of the fan. This method, like the second one described has the advantage of utilizing the heat that would otherwise be allowed to go to waste and hence of being cheap. It would also reduce the time required to cool the kilns which in some cases might be an advantage. The plant would have to contain a large number of kilns and be operated on a large scale in order for the cooling kilns to furnish enough heat to do all of the drying.

DRYING SEWER-PIPE AND HOLLOW WARE.

These classes of wares, on account of the shape of the individual pieces, are the most difficult to dry of all clay wares without cracking. The arrangement used most for these wares consists in using the different floors of the factory building as drying floors. The building is three or more stories in height and the floors are constructed of narrow lumber with narrow spaces, about an inch between the boards. The method of heating is by means of steam pipes, which are usually hung below each floor. The steam is usually exhaust steam during the time the engine is being run to operate the machinery and the rest of the time it is live steam. There is no means of ventilation provided for the escape of the warm air and hence there are no very well defined currents in the building. The tendency of the warm air to rise would, of course, give the highest temperature and fastest drying conditions on the top floor, a point that is taken advantage of by the operator in placing those wares that he desires should dry slowly on the lower floor.

DRYING OF POTTERY.

The drying of pottery, as a general thing, must proceed slowly on account of the shape and character of the ware. On account of this it is often set aside in an open room and allowed to partially dry after which it is placed on racks in rooms which may be closed and heated by means of steam or hot air.

BURNING.

After the ware has been dried by some one of the methods described above, it is removed to the kiln and stacked ready to be burned. The fuel used in burning may be wood, coal, coke, oil, or gas. In the drying process the water removed has been that which was added to the clay in the process of tempering it. The clay still contains hydroscopic moisture and chemically combined water. The first of these is driven off in the first stage of burning of the ware, while the latter requires a temperature of about 1,200 deg. F. There are a number of different kinds of kilns in use for the burning of clay wares, all of which belong

to either the continuous or the intermittent class. Each of these may be divided into two groups known as the up draft kilns and the down draft kilns.

BURNING OF BRICK.

Up Draft Kilns.—This is a very common type of kiln and is used almost entirely at the smaller yards for the burning of brick. There are many varieties of this type of kiln, some being temporary while others are permanent, some circular while others are rectangular. The one that has been used most extensively throughout the country is what is known as the scove kiln. In this type of kiln the brick are usually stacked first, and the walls are constructed later. The walls of the kiln are usually constructed of broken brick cemented together with mud, and the whole made tight so as to prevent the escape of the heat, and to prevent the air from entering the kiln except through the doors. On the top of the kiln a layer of green brick is laid flat and over these, and at right angles to them, is laid a layer of burned brick. These brick constitute what is known as the platting. In these kilns the brick are set up and burned in arches. These arches are unprotected from the fire and are closed by means of a door which is removed when fuel is added. The fires are built in the fireplaces or arches and the draft is, of course, up to the top. Fires are built in each end of the arches and the kilns gradually heated. Before the fire is started every alternate brick of the platting of burned brick is taken up and placed on end so as to leave an opening through which the smoke and vapors may escape. In some cases a wall of two thicknesses of brick containing a considerable amount of coal dust is built around the outside of the kiln. This coal dust acts as fuel in the burning and helps in bringing the temperature of the outer part of the kiln to that required to burn the brick.

The up draft permanent kilns differ from the scove kilns only in that they have permanent walls constructed out of burned brick. They are open at the top and ends, and these must be closed before the burning begins. These walls are in some cases as much as two feet thick at the base and taper to half that at

the top. In these side walls openings are left which lead into the arches formed in setting the green brick. The top of the kiln is covered in the same way as in the scove kiln. Kilns of this type are much used for the burning of common brick, but are very little used in the burning of the better grades of brick such as front brick or ornamental brick on account of the fact that the amount of salmon brick produced is large, amounting in some cases to as much as 35 per cent. The brick are set in the same manner and the burning proceeds as in the scove kiln. This type of kiln has an advantage over the scove kiln in that there is not so great a loss of heat, and that a greater percentage of the brick are of good quality. In the scove kiln in order to burn the brick in the outer part of the kiln those around the arches are frequently melted. The heat is radiated very rapidly from the scove kiln and can be maintained uniform only with the greatest difficulty. The walls are so thin that a strong wind may make it impossible to obtain the proper temperature on one side of the kiln so that the scove kilns can be operated successfully only under very favorable conditions. The principal thing in favor of the up draft kiln is the fact that it is cheaper to construct than the down draft ones, and is easier to keep in repair. There is, however, a large percentage of second grade bricks after burning.

Down Draft Kilns.—The down draft kilns differ from the up draft in the fact that the heat enters at the top and is carried down through the brick stacked in the kiln and out through openings in the floor of the kiln to the flues and through these to the stack or chimneys on the outside. In this type of kiln there are bags or pockets as they are called built along the interior to the top of the kiln. The lower end of these connect with the fire boxes and the heat passes through these bags and out at the upper end. The height of these bags on the inside of the kiln will vary, depending partly on the type of the kiln and partly on the individual opinion of the manufacturer.

The down draft kilns are constructed with one main stack, or there may be several small ones on each kiln. They may be built either rectangular or circular in shape. In some cases

they are built with two sets of fireplaces, the ones connecting with the bags on the inside and carrying the heat to the top of the kiln, and the other leading directly to the interior of the kiln. In this way the kiln may be worked either as an up or down draft one.

In the down draft kilns the heat can be much better regulated than in the up draft one and a more nearly uniform temperature may be obtained in the different parts of the kiln. In the down draft kiln the hottest part is at the bottom, and as the brick in this part of the kiln are also under great pressure they may frequently be completely ruined by being crushed and twisted out of shape. In the down draft kiln the brick at the top are subjected to the greatest heat and they are the ones under the least pressure so that they seldom become misshapen and may be readily sold for certain purposes. The percentage of salmon brick in a down draft kiln is much less than it is in an up draft. The capacity of down draft kilns varies, the average of the rectangular type being about 150,000 brick and the capacity of the circular type will vary with the diameter which is from about 15 to 30 feet.

Continuous Kilns.—There are a number of types of continuous kilns in use in various parts of the country. They all have several apartments or chambers which are separated by either temporary or permanent walls. The essential principles in the operation of all of these types are the same. They may be built circular, oval or rectangular in shape, and may contain a varying number of chambers. In all, the method of burning, consists in carrying the fire continuously around through a series of connected compartments. The prevailing direction of the draft may be either up or down. The chambers, which are in front of those in which the fires are burning, are filled with brick and are receiving the heat that is escaping from the chambers in which the fires are and in this way the brick are thoroughly dried so that they may be burned without danger when the fire reaches this chamber.

In starting the kiln a chamber filled with brick is first heated by means of the exterior fire boxes, and as long as the water,

smoke or steam is escaping the vapors are conducted direct to the stack. As soon as this ceases, however, the heat from this chamber is conducted through several others ahead of it before finally passing to the stack. In this way the escaping heat from any chamber may be used to heat others instead of being allowed to go to waste. The heat from a burning chamber cannot, as a rule, be carried through more than about three or four chambers before it is conducted to the stack and allowed to escape. The reason for this is the fact that the hot air absorbs a large amount of moisture, and if it is cooled down too much it will begin to deposit this and may soften the brick. Then, again, practice has shown that it is poor economy to reduce the temperature of the gases too low before they pass into the stack on account of the effect it has on the draft.

The method of firing these continuous kilns varies. In some it takes place through doors at the bottom, while in others coal slack is also fed in through openings in the top. Each chamber has a capacity of about 20,000 to 22,000 ordinary brick. In some of these kilns the chambers are separated by partitions made of brick and are permanent. In others the partitions are made of wood or heavy paper and burn out as soon as the temperature reaches that of red heat. The number of chambers in the kiln will be determined largely by the capacity of the plant.

The continuous kiln is the ideal method for burning brick and is the cheapest. They may be used for burning common and front brick, paving brick, and fire brick, and in some cases have been used successfully for burning the higher grades of clay wares. They are gradually coming into more general use throughout the United States.

BURNING OF SEWER-PIPE, DRAIN TILE, AND HOLLOW WARE.

Sewer-Pipe.—Sewer-pipe are usually burned in circular down draft kilns. The length of time required for burning usually ranges from four to six days. The pipe are set in the kiln in a vertical position with the smaller ones inside the larger, care being taken that they do not touch each other as this would pre-

vent their being glazed at the points of contact. When the temperature is highest they are salt glazed and allowed to cool for a few days after which they are gradually opened and completely cooled.

Drain Tile and Hollow Ware.—In the burning of these classes of ware almost any type of kiln may be used. The ware is placed in the kilns in a vertical position and in the case of the smaller sizes is very often placed in the kiln with brick and burned at the same time. The smaller pieces are set in the lower portions of the kiln and around the outside with the large in the center and at the top. In the case of drain tile they may be nested if several sizes are burned at one time.

BURNING OF STONEWARE.

Stoneware may be burned in either up draft or down draft kilns. The circular form is generally used. The articles are piled one on top of the other until the kiln is filled, the larger pieces being placed in the center and the smaller ones around the outside. The pieces are separated from each other by pieces of clay placed between them. The ware must be so placed as to give a good draft through the kiln. The length of time required to burn the ware will vary considerably and will depend, at least partly, on the character of the clay and on the size of the kiln. The temperature will also vary, depending on the character of the clay, and may range any place from about 1800 deg. F. to as high as 2300 deg. F.

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PART III

CLAYS AND CLAY INDUSTRY OF WASHINGTON

CHAPTER X.

GEOLOGY AND PHYSICAL FEATURES OF WASHINGTON.

It has been thought desirable to give a brief account of the geology of Washington as it is known at the present time, treating mainly of the character of the different formations found in the various parts of the state. So far but little accurate detailed work has been done on the geology of Washington, and hence our knowledge of the subject is far from complete. In a few localities, however, detailed work has been done in the last few years and hasty reconnoissance work has been done in others so that much more is known now than was a few years ago. This work has been done mainly by the U. S. Geological Survey and the results are found in the various publications. The State Survey which was in operation for a short time has done some work, the results of which are found in the two volumes published by it.

TOPOGRAPHY.

The topography of Washington is noted for its great diversity in character, and ranges from that in which the relief is very slight to that where it is very great. In the western part of the state are considerable areas that are only a short distance above sea level, while in the eastern part much of the surface is from 1,000 to 3,000 feet above sea level and in the central part through the Cascade mountains altitudes of from 3,000 to 6,000 feet are very common, and isolated peaks such as Rainier, Adams, St. Helens, and Baker range from 10,000 to 14,363 feet above sea level.

These great differences in topographic features cause the climate to be very different in the different parts of the state. On the western side of the Cascade mountains the climate is mild, with a considerable amount of rainfall, while on the eastern side of these mountains the amount of precipitation is less and

the range of temperature, that is the difference between the extremes of summer and winter, is greater.

Not taking into consideration the minor features, Washington may be conveniently divided, topographically, into seven distinct areas as follows: The Coast mountains, Olympic peninsula, Puget sound basin, Cascade mountains, Okanogan highlands, Columbia plain, and Blue mountains. These different areas are not separated by any fast and hard lines, but merge insensibly one into the other. In their main topographic features, however, they are quite distinct. The accompanying relief map of Washington (Plate I) shows fairly well these different topographic areas.

OLYMPIC PENINSULA.

Topography.—The Olympic peninsula comprises the extreme northwestern part of Washington. It is bounded on the north by the Straits of Fuca; on the east by Admiralty inlet, Hood's canal, and other parts of Puget sound; on the south by arms of Puget sound and the Chehalis river; and on the west by the Pacific ocean. The most striking topographic feature of the peninsula is the Olympic mountains. These consist of a mass or group of mountains of almost circular outline, the central part of the mass being situated a little to the north and east of the central part of the peninsula. This group of mountains culminates in Mount Olympus, which has an altitude above sea level of 8,150 feet. From this the other mountains, many of whose summits rise to altitudes ranging between 6,000 and 8,000 feet, radiate in all directions.

The Olympic mountains have not been very thoroughly explored, and on account of this the amount of reliable information in regard to them is not great. They are very rough and rugged and difficult to explore. They are so situated that they receive a large amount of precipitation in the form of rain or snow, and on account of this there are many streams flowing from them. These streams have cut deep steep sided gorges along which they flow rapidly. In many cases the sides of these canyons are so steep that it is not possible to ascend them. The divides between the streams are very narrow and sharp.

On the south, west, and north sides these mountains are bordered by a narrow strip of low land which has an entirely different kind of topography from that of the mountains. Here the land is low and much less rough than that already described.

Geology.—Very little is known in regard to the geology of the Olympic peninsula. Until very recently the Olympic mountains have been generally considered as being composed mainly of igneous and metamorphic rocks of unknown age. Some doubt, however, has been thrown on this point by Arnold*, Conrad†, and Dodwell and Rixon‡. All of these parties have been in the Olympics recently. Conrad saw no sign of vulcanism, Dodwell and Rixon saw no granite or porphyry, while Arnold thinks that at least the greater part of the Olympics is composed of sandstone. According to Arnold|| the costal region is made up of serpentine, old diabase, metamorphosed sandstone, quartzite, sandstone, shale, basalt and basalt tuffs, conglomerate, till, clay, and gravel.

COAST MOUNTAINS.

Topography.—The coast mountains are situated in the southwestern part of the state and have an area of about 2,500 square miles. These mountains are so situated that they receive a large amount of precipitation and are well supplied with streams. The altitude is from sea level to as much as 1,500 to 1,800 feet above. On the whole it is a rather rough area; the streams having cut deep gorges. The divides between the streams are not so sharp and jagged as they are in the Olympic mountains. The rocks are mostly soft sedimentaries and this has determined very largely the character of the topography.

Geology.—Scarcely any study of the geology of this region has been made and hence but little is known in regard to it. The main part of the area is made up of sedimentary rocks which belong to the late periods, geologically, in the earth's history. Sandstones, shales, and rocks of this character predominate. On

*Bull. Geol. Soc. Am. Vol. XVII, p. 457.
†Science N. S. Vol. XXI, March 10, 1905, p. 392.
‡Professional paper, U. S. Geol. Survey, No. 7, 1902, p. 19.
||Bull. Geol. Soc. of Am. Vol. 17, p. 459.

the south side of this area along the Columbia river the rock is basalt. Fossils have been found in a few places in these mountains.

PUGET SOUND BASIN.

The Puget sound basin, as the term is used here, is intended to include all of the depression between the Cascade mountains on the east and the Olympic and Coast range of mountains on the west and extends from north to south across Washington.

Topography.—The topography of the basin, as thus defined, differs considerably in its various parts, being quite different in the northern part from what it is in the central part, while in the southern it is unlike either of the others. In the north and northwestern part of this basin are a number of islands, many of which rise to a considerable distance above sea level and are in some cases rough and mountainous. These islands are composed of hard rocks which have been weathered into forms characteristic of this kind of material.

In its central part the Puget sound basin contains a large amount of glacial material, and its topographic features have been carved in this material. These glacial deposits fringe the Cascade and Olympic mountains on either side of the basin and rise as much as 1,000 to 1,200 feet above sea level. The topography through the central part of the basin where these glacial materials occur is of the plateau type. The main elevations are flat topped, have steep slopes, and rise abruptly from alluvial plains or from the waters of the sound.

The altitude of these major elevations varies more or less in different localities, but in the central part of the basin along its axis they range from about 300 to 500 feet. The depressions between these high, flat topped elevations are very prominent topographic features of this part of the sound basin, and in many cases these extend below sea level and have been filled with water and constitute the Puget sound. In the southern part of the basin the glacial material does not occur, and the topography is such as is formed by the weathering and erosion of soft sedimentary rocks. In the main the elevations are not

great, the ridges are low and have gentle slopes, and the valleys along the streams usually have considerable width.

Geology.—The geology of Puget sound basin, like the topography is different in the northern part from what it is in the central part and both differ from that in the southern. In the northern part are found the oldest sedimentary rocks that have been found in the basin so far. These are of Cretaceous age, and consist mainly of sandstones and conglomerates. At a number of places on some of the islands in this part of the basin limestones in greater or less amounts are found.

In the central part of the Puget sound basin the formations exposed on the surface are almost entirely of glacial origin. The floor on which this glacial material has been spread out is mainly sedimentary rocks which are largely of Eocene age. After the sediments of which these rocks are formed were deposited they were folded and faulted, and this made the floor of the basin rough and irregular. These irregularities, however, do not show on the surface at the present time, partly because they have been reduced by atmospheric agencies, and by the action of glaciers in cutting them down, and partly because they have been covered over with the material deposited by the glaciers. The formations in this part of the basin consist mainly of sandstone, shale, conglomerate, and glacial material such as gravel, till, and clays. The glacial material occupies the larger part of the area and covers the other deposits almost completely. The glacial deposits throughout this part of the basin are one of the sources of the clays that are being used here. In addition to these glacial clays there are also clays and shales, which are found in connection with the coal beds in this locality, that are being used in the manufacture of various kinds of clay products.

In the southern part of the Puget sound basin the glacial material is mostly absent, and soft sandstones and shales of late geological age appear on the surface. These deposits have furnished clays which are being worked at a few localities, the principal one being Little Falls.

CASCADE MOUNTAINS.

The Cascade mountains extend from north to south across Washington and constitute the most marked topographic feature of the state. The range has its greatest width at the northern and southern boundaries of Washington, and is the narrowest in the central part of the state. On the west it merges into the Puget sound basin while on the east it is bordered by the Okanogan highlands and the Columbia plain.

Topography.—The Cascade mountains may be separated into two distinct topographic areas. These two parts of the range differ also in the character of the rocks of which they are composed. In the southern part of Washington the individual peaks reach the greatest altitude, Mt. Rainier being 14,363 feet above sea level. The average height of this part of the range, however, is not so great as is that of the northern part. The streams which drain the Cascade mountains in the southern part of Washington flow either directly into the Pacific ocean or else into the Columbia river, and through this to the Pacific. These streams have cut deep gorges and in some cases have formed narrow valleys along a part of their courses. The divides are sharp and the slopes steep. The amount of erosion on the eastern side of the range has not been as great as it has on the western side, partly on account of the fact that the amount of precipitation is greater on the west, partly also to the fact that the streams on this side of the range, as a general thing, are shorter and flow more rapidly than they do on the eastern side. In the southern part of the state along the Columbia river the range has a width of about 100 miles.

In northern Washington the streams which drain the western slope of the Cascades empty into Puget sound, are short and flow rapidly. They have cut very deep gorges almost to their sources. The valleys as a general thing along these streams are narrow, the divides between the streams high and sharp with steep slopes. One of the very marked features in connection with this part of the range is the abruptness with which the mountains rise from the low land on the west. In northern

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Washington the Cascades range in height from 6,000 to 8,000 feet with individual peaks which are even considerably higher than this. There is a very marked uniformity in height of the main peaks and ridges of these mountains in the northern part of Washington. So marked in fact is this feature that it is thought that these peaks and ridges represent the remnants of a great plateau from which the range has been carved. There is a large amount of precipitation over this area and hence there are many large streams which have cut deep gorges and produced an extremely rugged topography.

Geology.—In southern Washington the Cascades are composed very largely of volcanic rocks with sedimentary deposits along the foothills on the western slope. These sedimentary deposits are mostly sandstones and shales, and so far as known at present are all of Tertiary age. Granites are reported as occurring in some places in the Cascades in southern Washington, and according to Smith,* granite forms an elevated plateau on which the volcanic cone of Mt. Rainier has been built up. The volcanic rocks are lavas, breccias, tuffs, and agglomerates.

The Cascade mountains in northern Washington are composed of sedimentary, igneous, and metamorphic rocks of various kinds. In many cases the sedimentary rocks have been highly metamorphosed, while in others they are very little changed. The sedimentary rocks may be separated into two classes as regards age, namely, those of pre-Tertiary and those of Tertiary. These pre-Tertiary sedimentary rocks are conglomerates, sandtsones, shales, and limestones and are exposed over considerable areas near the Canadian boundary.† The Tertiary deposits are mainly sandstones, shales, and conglomerates, and are thought to be of fresh water origin, as no marine fossils have been found in them, so far. The age of these beds has been determined largely by the fossil plants that occur in them.

Metamorphic rocks are very common in this part of the Cascades. They are mainly schists, gneisses, and slates, and their

*18th Ann. Rept. U. S. Geol. Survey, pt. II, p. 423.
†Russell, 20th Ann. Rept. U. S. Geol. Survey, pt. II, p. 128.

age is not known. Igneous rocks are common throughout the northern Cascades and consist of granites, diorites, and rocks of this character. They are found as intruded masses occurring in the metamorphic rocks and their age is not known. Lavas and tuffs are also found at various places in this part of the Cascades.

The oldest sedimentary rocks in this part of the range, the age of which has been determined by means of fossils, is the Cretaceous. The later formations are found at a number of places, and flank the western side of the range from the northern to the southern boundary of the state.

Granites are found in many places in the Cascade mountains of northern Washington. At Index, on the western slope of the range, is a large area of granite. This granite is light colored, and is composed largely of quartz and feldspar with some biotite and hornblende. The summit of the range where the Great Northern Railway crosses it is also granite. Granite also occurs along the Skagit river above Marble mountain. Granites are found at a number of other places along the western slope of the Cascade mountains, but their extent is not well known.

Granites are common along the eastern slopes of the Cascades in northern Washington. Large areas occur around Mt. Stuart where they have been shown by Smith* and Russell† to be intrusive. This is a light colored granite, and is composed of feldspar, hornblende, and mica. Large granite areas occur around Lake Chelan and north of there in a number of places. In fact granites are very common in the Cascade mountains in northern Washington and form a considerable part of the range.

OKANOGAN HIGHLANDS.

The term Okanogan highlands includes that part of Washington lying north of the Columbia and Spokane rivers and east of the Cascade mountains. To the east they extend to the eastern border of the state and join the mountains of Idaho. To the north they extend to the northern boundary of the state.

*Professional paper No. 19, U. S. Geol. Survey, p. 21.
†20th Ann. Rept. U. S. Geol. Survey, pt. II, p. 108.

Topography.—This area is all some distance above sea level and is drained by a number of good sized streams which flow in general north and south directions across it. The principal ones are the Columbia, Okanogan, Pend d'Oreille, Colville and Sans Poil. There are also a number of smaller streams in the district so that it is well drained. The main streams flow in rather deep depressions which, in some cases, are narrow canyons. Along some of the streams valleys having considerable width have been formed. In the western part of this area the hills are low and broad with gentle slopes. This is especially true of that part between the Okanogan and Columbia rivers. The larger part of the area between these two streams has the appearance of a gently undulating plain with very gently sloping hills. The average height of this part of the Okanogan highlands is not more than about 3,500 feet.

That part of the Okanogan highlands east of the Columbia river is much more mountainous and rougher than that part to the west of it. Here the divides between the main streams are quite prominent mountain ridges. Between the Columbia and Colville rivers there is a mountain range which in cases reaches an altitude of as much as 5,000 to 6,000 feet above sea level. The lateral streams have not dissected these mountains greatly and they have a gently rounded outline instead of sharp jagged peaks and steep slopes. The ridges to the east of the Colville and Pend d'Oreille rivers are very similar to the ones just west of the Colville river except that perhaps they are a little higher and rougher.

Geology.—In some ways the geology of the Okanogan highlands is very similar to that of the Cascade mountains in northern Washington. The rocks are principally igneous and metamorphic and consist mainly of granite, gneisses, schists, crystalline limestone, quartzites, slates and rocks of this character. Many veins of pegmatite are reported by Landes* as occurring between Curlew and Midway. He also says that Mt. Bonaparte,

*Washington Geol. Survey, Vol. I, p. 18.

in Okanogan county, stands in the center of a large granit area. Granite also occurs along the divide between Curle creek on the west and the Kettle and Columbia rivers on the eas It occurs at places also in the mountains between the Columbi and Colville rivers. The ridges to the south of Loon lake ar composed of granite which contains a large amount of feld spar. Mount Carlton to the northeast of Spokane forms th center of a large granite area. In places these granites ar very coarse-grained and are composed mainly of quartz an feldspar with some muscovite. Granites probably occur i many other places throughout this area as the geology has bee but little studied and but little is known in regard to it. Gneis is very common in the western part, especially, of the Okano gan highlands. Andestites are also quite common in parts o this area.

In the northeastern part of this area crystalline limestone are very common. In many places these are very coarsel crystalline and have been highly metamorphosed. Slates are o common occurrence in the mountains around Colville. Asso ciated with the slates in this locality are igneous rocks of var ious kinds, serpentines, limestones, and quartzites. The age o all of these igneous and metamorphic rocks is not known.

Sedimentary rocks are known to occur in but few places in the Okanogan highlands. In the town of Republic, Ferry county, are some sedimentary deposits from which fossil leaves have been collected and the age of these beds, based on this evidence, has been given by Knowlton* as somewhere near the middle Tertiary. These same deposits occur in several places a short distance to the north of Republic.

COLUMBIA PLAIN.

The Columbia plain includes that part of Washington situated east of the Cascade mountains, south of the Columbia and Spokane rivers and extends on the east to the Idaho line and on the south to the Blue mountains and the northern boundary of Oregon.

*Washington Geol. Survey, Vol. I, p. 33.

Topography.—Surrounding the Columbia plain on all sides are mountains which rise above it and make it a basin. The drainage from this basin finally reaches the Pacific ocean through the Columbia river. The altitude of this part of Washington ranges from about 380 feet at Pasco to about 2,500 to 3,000 feet along its northern and eastern borders. The streams draining that part of the plain that is to the east of the Columbia river flow in a general southwesterly direction, and the general slope of the surface of this part of the plain is in the same direction. The principal stream which flows across this area is the Snake river. This stream, for a considerable part of its course across the area flows in a deep narrow gorge. In places this gorge has been cut as much as 2,500 feet deep in this plain, and the sides of the gorge are steep and precipitous. All of the principal streams which flow across this part of the state have cut deep gorges. The action of the atmospheric agencies has not broadened them very much and they are still steep-sided and narrow. The lateral streams are short and are not very well developed.

In the main this part of the state has the appearance of a plain, and the deep canyons along which the streams flow are not visible to a person looking at the country from any of the higher points on the plain. At different places in the Columbia plain are small areas that rise to a considerable altitude above the general surface of the plain. One of the most noted examples of this is that of Steptoe butte. This is a conical butte which rises about 1,000 feet above the surrounding country and is a very prominent landmark throughout southeastern Washington. The surface of all this area is more or less irregular and the larger part of it is covered with hills which rise from a few feet to as much as 90 feet above the general surface of the plain.

That part of the Columbia plain which is west of the Columbia river is quite different in its topographic features from the rest of the plain. Here we have broad valleys with high ridges between, and these in general trend east and west and transversely to the course of the main stream, the Yakima river. The

valleys in this locality are of two distinct types, according to Smith,* some of them being structural while others are due to erosion. The rocks in this part of Washington have been thrown into a series of gentle anticlines and synclines, the valleys occupying these synclines. In the case of the Yakima river, however, the conditions are somewhat different. Here the stream has cut across these ridges and formed a valley of erosion.

Geology.—The principal rock exposed on the surface of the Columbia plain is basalt. This covers the older rocks in many places to a great depth. In a few places older rocks come up through this basalt. These rocks are granites, gneisses, schists, and quartzites. In the western part of this area some sedimentary deposits of Miocene† age are found occurring on the surface. They are sandstones, shales and conglomerates.

Granites and gneisses are exposed at but few places on the Columbia plain. A few miles south of Spokane is the largest area of these rocks exposed in this part of Washington. Here the granite extends above the plain in quite prominent hills, the highest, Mica peak, being 5,200 feet above sea level and about 3,200 feet above the surrounding country. The rocks of which these mountains are composed are more liks a gneiss than they are a true granite. They are composed mainly of quartz, feldspar, and mica. They are on the whole coarse grained and have the appearance of having been very much changed or metamorphosed. They are especially important as they have been decomposed in places to form quite extensive clay deposits which are being utilized at a number of places at the present time. Granites occur also at Medical Lake and a little above Wawawai on the Snake river.

BLUE MOUNTAINS.

That part of the Blue mountains that is in Washington occupies the extreme southeastern part of the state. They are bordered on the north and east by the Columbia plain.

*U. S. Geol. Survey Atlas, Folio No. 86, p. 5.
†Smith, U. S. Geol. Survey Atlas, Folio No. 86, p. 3.

Topography.—These mountains have been carved out of an elevated plateau by stream erosion, and the action of atmospheric agencies. They have an altitude of from 6,000 to 7,000 feet above sea level and from 3,000 to 4,000 feet above the Columbia plain on the north. The main streams draining these mountains have cut deep canyons along which they flow and the lateral streams are also well developed, reaching back to the summits of the divides. Weathering agents have also been very active in broadening the canyons until now the area is one of deep canyons and very sharp divides.

Geology.—The main rock throughout the Blue mountains of Washington is basalt. In a few places along the canyons the older metamorphic formations are exposed. These consist mainly, so far as known at present, of schists and limestones.

CHAPTER XI.

CLAYS OF WASHINGTON.

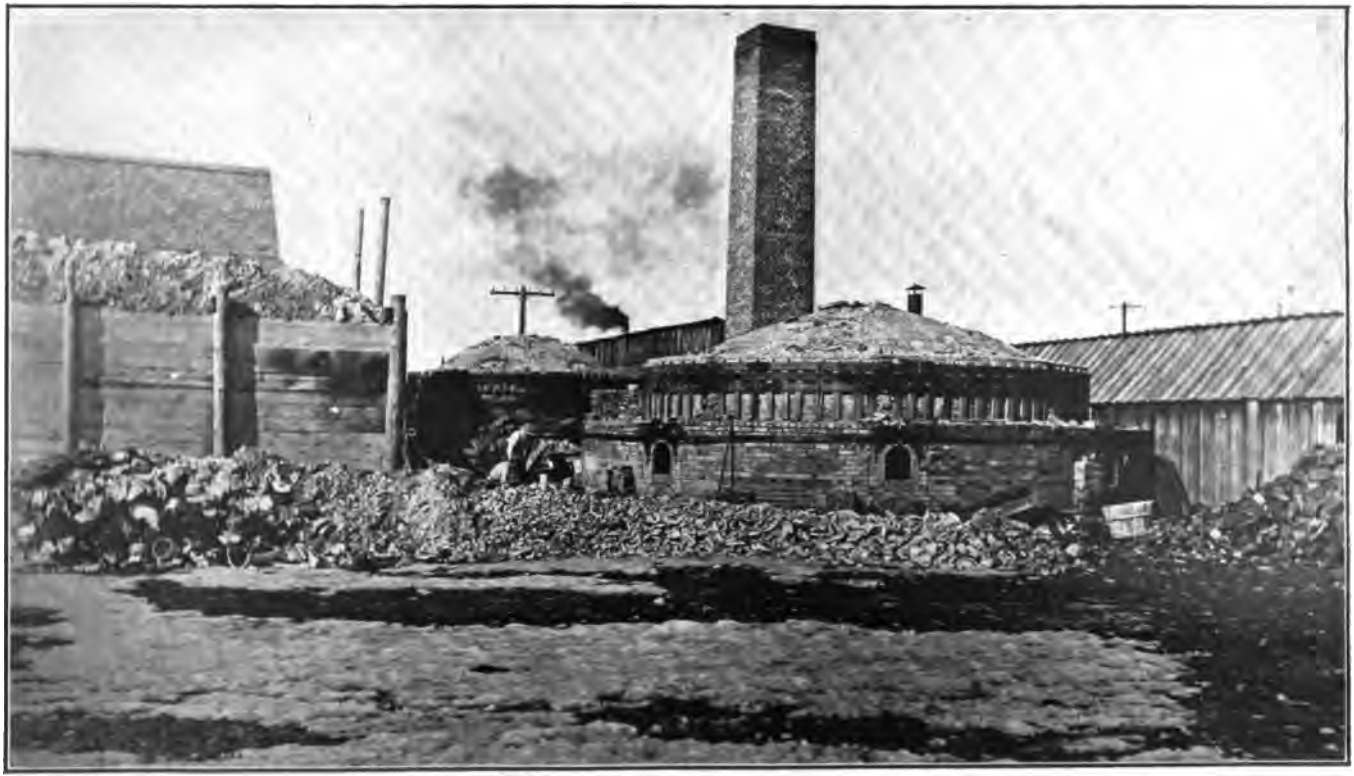
Clays as already explained are secondary products which have been formed by the decomposition of various rocks and minerals, and vary in composition on account of the fact that the rocks and minerals from which they have been formed have differed in composition. The best grades of clay, such as kaolin or china clay, and high grade fire clay, are usually formed from the decomposition of feldspars, or from those rocks which contain a large amount of feldspar, and are practically free from iron and the alkalies.

Based on the position which they occupy as regards the rock or minerals from which they have been formed, clays may be separated into two classes as follows: Residual clays or those that remain in the place where they have been formed, and transported clays or those that have been removed from the place where they formed and carried for a greater or lesser distance by some agency such as streams, glaciers, wind, etc., and then deposited. The clay deposits of Washington belong to both of these classes and both of them are important. The transported clays are being used more extensively at the present time, however, than those that are strictly residual.

RESIDUAL CLAYS.

The principal kinds of rocks which, through their decomposition, contribute to the mass of clays in Washington may be conveniently grouped as follows:

1. Granite and gneiss.
2. Basalt and allied basic eruptives.
3. Sandstones.
4. Shale.
5. Metamorphic limestones, dolomite, and schists.



PLANT OF THE SPOKANE POTTERY, CLAYTON

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Granite and Gneiss.—These rocks on account of having a considerable amount of feldspar are very apt to produce high grade clays when they decompose. As shown in the preceding chapter these rocks are of quite common occurrence throughout Washington, but only in a very few places have they formed residual clay. South of Spokane and to the east of it in the granite area of which Mica Peak is the highest point, the rocks have decomposed in places to form a considerable thickness of residual clay.

The rocks throughout this locality are very rich in feldspar, and do not contain a large amount of the ferro-magnesian minerals such as hornblende and biotite. These rocks have been highly metamorphosed, and are properly, perhaps, gneisses rather than granites. They are peculiar also in that the different minerals seem to have segregated out from each other and collected in zones so that in places when they decompose there are seams of almost pure kaolinite. These seams vary much in thickness and range from less than an inch to as much as two or three feet. In places these rocks contain a large amount of quartz, and when they decompose, the result, so far as this part is concerned, is almost pure sand. In other places the rocks are very micaceous, and when they decompose the resulting clays contain a large amount of mica. Some are of a deep red color showing the presence of a considerable amount of iron. This may have been derived from the decomposition of ferro-magnesian minerals which were present in the granites and gneisses, or it may have come from the basalt which covered at one time the foot hills of this area of crystalline rocks to a higher altitude than it does now.

Residual clays are formed only under certain conditions. They do not form on steep slopes on account of the fact that in such a position the material is removed as fast as the rock decays, and then is transported clay. When rocks come to the surface where the slope is very gentle, or the surface is practically level, decomposition begins, and soon a layer of decomposed rock or clay covers the rocks. In some cases this decomposition goes on until a layer many feet in thickness has formed.

Residual clays, as a general thing, are better clays than those that have been transported for long distances by streams, as they contain less impurities. This is due partly, at least, to the fact that they have been derived more nearly from one kind of rock and there has not been the same chance for impurities of various kinds getting mixed with them. Wherever granites and schists or rocks which contain a considerable amount of feldspar occur good high grade clay may be found.

Basalt and Allied Basic Eruptives.—These basaltic and allied basic eruptive rocks are very common in Washington, and throughout the eastern part of the state especially, the basalts have been the source of large deposits of residual clays. These rocks contain less of the feldspars, than do the granites and more of the ferro-magnesian minerals, and when they decompose they form clays with a considerable amount of iron in them. These clays are also very apt to be below the average in alumina. The percentage of these different substances, however, will vary more or less as the composition of the rocks from which they are derived varies. In many places throughout the basaltic region of the state these clays are used for the manufacture of common brick, and in some places for drain tile also. If properly handled they make very good brick and tile, and in some cases a very good repressed brick is made from them. Clays suitable for the manufacture of the higher grades of ware are not formed, however, by the decomposition of rocks of this character.

Sandstones.—Sandstone is made up of grains of quartz bound together by some cementing substance such as silica, iron oxide, or calcium carbonate. On account of its composition it does not contribute very largely to the formation of clay. The weathering of a sandstone is mainly the loosening of the grains of sand or disintegration and the residual deposits are mainly sand. The percentage of kaolin in most sandstones is very small, and they are not usually classified as clay forming rocks. In places in Washington the sandstones are common, and in these parts of the state residual clay deposits would not be expected to occur in very great abundance.

Shale.—The shales are really more or less hardened sediments that have been transported by the streams and then deposited in water. They usually contain all the elements found in an alluvial clay. They may contain large or small amounts of such minerals as kaolinite, quartz, iron, etc., and the different minerals and the proportion in which they occur will determine as to whether the shale is suited to the manufacture of certain clay products. In some cases the composition is such that the shales are of very little value for the manufacture of anything.

These shales, when they weather and decompose, may form residual clays which have practically the same composition as the shale itself. This is due to the fact that the weathering in this case is principally a loosening and separating of the grains, and is a mechanical change with but very little chemical change taking place. Should this be removed and transported for a considerable distance by running water and redeposited, then the composition of this new clay might be quite different from the shale on account of the introduction of material from entirely different sources. On account of the hardness of these shales they must either be allowed to weather or else be pulverized artificially before they are used.

Shales are found at a number of places in Washington, some of which are being used at the present time for the manufacture of paving and common brick. There are probably plenty of other places in the state where just as good shales occur, that are not being used. Shales are common in the coal formations throughout Washington.

Metamorphic Limestones, Dolomites, and Schists.—Limestones and dolomites usually contain but very small amounts of the minerals, such as kaolinite, silica, iron, etc., that go to make up the principal part of a clay. In the decomposition of the limestone or dolomite the calcium and magnesium carbonates are taken into solution, and more or less completely removed by under-ground waters and the other minerals remain and form a residual clay. The clay may vary widely in composition on account of the rock from which it has been formed varying in

composition. It may contain a large or small amount of kaolin, be high or low in silica, and contain variable amounts of such minerals as iron oxide, calcite, etc.

Limestones and dolomites are found quite abundantly in the northeastern part of the state and some clays may have been formed from them in this locality.

Schists when they decqmpose may produce clays. The clays produced from these would vary much in composition on account of the great variation in the composition of the rocks classed under this head. The clays formed from the decomposition of the schists would be suited to the manufacture only of the lower grades of clay products.

As shown in the preceding chapter schists are very sommon rocks in certain parts of Washington and in these localities nothing but the poorer grades of clay are apt to occur.

Form of Residual Deposits.—The forms that these residual deposits take vary a great deal, and depend on the shape of the rock mass from which they have been formed. If we have a great mass of granite, or rock of such a character that when it decomposes it yields a clay, then the residual clay may cover a considerable area. If the clay is derived from some rock such as pegmatite, quartz, and feldspar, which occurs in the form of veins where the width is small compared with the length, then the outcrop of the residual clay along the surface will form a narrow belt.

The depth of a residual clay deposit will depend on a number of things such as climate, character of the rock, and topography. The decay of most rocks takes place very slowly, can hardly be measured in years, and is scarcely noticeable in the lifetime of a person. The climate has much to do in determining the rate of decay of rocks, and other things being equal, rock decay goes on fastest in a moist climate; hence the greatest thickness of residual clay should be looked for in such regions. In Washington the Cascade mountains separate the state into two distinct climatic regions, that part situated on the west side of the mountains having a much larger amount of precipitation than that on the east side. Other things being equal,

residual clay deposits should form faster on the west side than on the east side. The other conditions, however, are not the same now, and have not been in times past, and we find the best residual clays in eastern Washington instead of western.

Some rocks decay more rapidly than others, and hence the character of the rock may determine the thickness of the residual clay. In the case of some few shales the change may be quite rapid. The topography is an important factor in determining the thickness of a residual clay. If the slope is steep the clay may be removed as fast as it forms, while if the slope is gentle, or the surface flat, much at least of the clay will remain in place after having been formed.

The color of the residual clays varies much on account of the variation in the composition of the rocks from which they are derived. If the rock contains a large amount of iron the clay may be red, yellow, or brown, depending on the compounds of iron that are present. Where iron is absent, or occurs only in very small amounts, the clays are white. These clays may be of almost any color, however.

TRANSPORTED CLAYS.

In most cases the conditions are such that the clay, formed from the decomposition and disintegration of the various kinds of rocks, is removed from the place where it formed by means of some agency and transported for a greater or lesser distance. The clay which forms on the tops and slopes of hills and ridges gradually works down into the adjacent valleys. Very heavy rains aided by gravity may cause large quantities of this clay to move down these slopes, and as a result of these movements of residual deposits it is not an uncommon thing at all to find valleys filled to a considerable depth with the clay from the neighboring slopes. Much of this clay may find its way by this means into the streams and be transported for long distances before it is finally deposited.

The power of a stream to transport this clay material depends on the velocity of the stream, and as long as this remains the same the material which the stream has in suspension

will be carried along. If, for any reason, the velocity of the stream should be checked so that the water becomes quiet, then the clay particles begin to settle to the bottom to form a clay layer which may be added to, from time to time, until finally we have a deposit of considerable thickness that is made of a number of different clays. To such the term sedimentary clay is applied. The conditions under which a thick bed of sedimentary clay has been formed have not been the same all the time, and on account of this the character of the material, that is as regards the coarseness or fineness of it, has been different at different times, and the deposit stratified, or made up of layers.

The rocks of adjacent hills are frequently of different kinds, and when these decompose they may each furnish a part of the material for a sedimentary clay and on account of this fact these clays are apt to be suitable for the manufacture only of the common grades of clay products. Sedimentary clays may usually be distinguished from residual clays by this stratification, and also on account of the fact that they usually have no direct relation to the rock on which they rest.

CLASSIFICATION OF SEDIMENTARY CLAYS.

The general character of the sedimentary clays is more or less determined by the conditions under which they formed. On account of this the sedimentary clays of Washington may be divided into the following classes:

1. Estuarine clays.
2. Glacial clays.
3. Marine clays.
4. Lacustrine clays.
5. Flood plain and terrace clays.

Estuarine Clays.—The estuarine clays represent those that have been formed in shallow arms of the sea. On account of this they are apt to occur over long and comparatively narrow areas. Streams carrying sediments empty into these estuaries, and these sediments are deposited and clay beds are formed. In case strong currents prevail in parts of the estuary the fine sediments will not be deposited at these places, and might be

carried on through the estuary and out to sea, and form marine deposits. If the estuary should be supplied by a single stream of low velocity which enters at the upper end of it then the coarsest material will be found at a point nearest the mouth of the stream, and become finer until a point is reached where the purest sediments occur.

In Washington during the Eocene period an arm of the sea or estuary covered a large area where the Puget sound now exists and extended along the eastern slope of the Cascade mountains and probably connected in some way with the water body on the east side of the range around Roslyn. The exact boundaries of this body of water, however, are not definitely known, This was the period when the conditions in this part of the state were favorable and large deposits of coal were formed. The fossils that have been found in these deposits are such as live only in fresh or brackish water, which would go to show that at times it was connected with the sea and then again would be separated for a time and become fresh water again. During this time, according to Willis,* a thickness of 10,000 feet of shallow water deposits accumulated. Throughout the entire thickness of these deposits are seams of coal. The formation consists of sandstones, shales, slates, and coal.

At the time the coal was forming the area was probably marshy and swampy and the climate warm and mild, favoring a dense, rank growth of vegetation which accumulated in sufficient quantity to form our present coal beds throughout this part of the state. During the whole of the Eocene period there must have been a gradual subsidence taking place over this part of the state, but the rate of this sinking was not the same at all times. On account of this fact the depth of the water varied at different times and hence the character of the deposits that were accumulated in any one place varied.

When the rate of subsidence was less than the rate of building up by sedimentation the result would be that the basin would be filled in until the bottom would be brought to the sur-

*Tacoma Folio, U. S. Geol. Survey, No. 54, p. 2.

face of the water and form a marsh. Vegetation spread over this and a layer of it accumulated, and then the rate of subsidence increased and this sank below the surface of the water again and a layer of sediment was formed over it. This was repeated many times during the period, as is shown by the large number of coal seams found in these deposits.

The character of the sediments deposited at any time depends on the conditions. At times coarse deposits, such as sandstones were formed, then conditions changed and a layer of very pure material was laid down over this and a shale was produced so that now we find sandstone, shale, and coal alternating.

These shales which are found in connection with the coal deposits in this part of Washington form one of the state's most valuable materials from which to manufacture certain kinds of clay products. At the present time these deposits are being worked at but very few places. They occur very extensively, however, along the western side of the Cascade mountains from the northern border of Washington to as far south at least as Green river. Shales are very common throughout this entire district and while the different outcrops have not been examined, there are undoubtedly many places where the deposits are as well suited for use in the manufacture of the various grades of clay products as those that are being used at the present time.

Glacial Clays.—In Washington during a part of the Quaternary period that part of the state situated between the Olympic mountains on the west and the Cascade mountains on the east and extending south to a little beyond the 47th parallel was covered with ice. The glaciers appear to have formed in the Cascade and Olympic mountains and to the north in British Columbia. The ice in British Columbia moved to the south and combined with that from the mountains and spread out and covered the whole of this country and glacial clays are distributed irregularly over a large part of it. Wherever any of the moraine deposits occur more or less of the glacial clays are found.

Throughout the sound country this clay is usually of a bluish color. In many places it is mixed with pebbles and boulders

S. Shedd, Photo STORAGE SHED OF THE SPOKANE POTTERY, CLAYTON

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of various shapes and sizes and on account of this is of no commercial value for clay ware. In some cases, however, even where there are quite a good many pebbles mixed with the clay it is used by first passing it through a crusher so arranged that it will remove the larger stones and crush the smaller ones. In one or two yards around Seattle no attempt is made to get rid of these pebbles and the result is that a very rough brick is made. In case the clay contains nothing but large boulders these may readily be removed by hand.

In some cases the deposition of these clays has been modified more or less by the action of water and they are stratified. In such cases they have been carried by the streams which issue from the foot of the glaciers and deposited along flood plains or in lakes. The material of which these clays are composed was derived from the ice, but since they have been deposited by water they may be classed just as appropriately perhaps under almost any of the other sedimentary deposits.

The glacial clays in Washington are tough, plastic, low grade clays suited only for the manufacture of the commonest of clay wares. They are used at many places around the largest cities on the sound for the manufacture of common brick, hollow brick, fire proofing, and articles of this kind.

Marine Clays.—The marine clays include those sedimentary clays which have been deposited on the ocean bottom. They are laid down where the water is practically free from currents, and hence are usually formed some distance from the shore where the water is comparatively deep. These deposits have usually been hardened more or less and appear on the surface as shales. They frequently cover large areas and are of great thickness. They usually vary much, however, in the different parts of the deposit, on account of the material being brought from different places by streams, and from where the rocks are different.

During the Eocene time that part of Washington south of the present Puget sound and west of the Cascade mountains was a part of the Pacific ocean, and the streams from the land area

which probably existed where the Cascade mountains are, were carrying large quantities of sediments out into the ocean and depositing them. These were hardened into shales and at the present time are found throughout this part of the state either as shales, or clays which have been formed by the decomposition of these shales. So far these deposits are worked at only one place, Little Falls, where quite a large plant has been located. There are numerous other places, however, where in all probability just as good material may be had as that at Little Falls.

Lacustrine Clays.—The lake clays are those that have been deposited in basin-like depressions which were occupied by lakes or swamps. This class of clays is very common in many places, but so far as the author is aware occurs in but few places in Washington where they are of commercial value and are being utilized.

The clays which occur around Clayton to the north of Spokane are of this class. At this place there is a flat level tract of land which is almost completely surrounded by higher land and in some cases there are hills which rise to a considerable distance above it. These hills are composed of granite, and the decomposition of this has furnished the clay which was deposited in the lake, and finally filled it. The deposits show well marked stratification and in places well preserved fossil plants occur in them. Their age has not been determined.

Flood Plain and Terrace Clays.—In the case of many streams terraces border them on one or both sides. These are formed mostly along those streams that are down practically to a base level, and are winding back and forth across the valley and broadening it. There may be a number of these terraces, one above the other, and each one represents a former flood plain, and this shows that the stream at different times has been at those levels, and has cut its bed down to where it is at present. Only in the case of the slow sluggish stream, or in places along the course of the stream where the current is checked, and the water becomes practically still, will sediments be deposited.

In Washington most of the streams are some distance above

sea level and are comparatively rapid streams, and hence clay deposits are not so common along them as they are in some places. Such deposits do occur along some of the larger streams such as the Columbia, Pend d'Oreille, Yakima, and Skagit rivers. Near Northport, on the Columbia river, is a clay bed of this character that is used as a glaze for pottery. Along the Pend d'Oreille large deposits of this character occur at several places. These terrace clays are apt to vary much in composition and physical properties and only in a few places is it probable they will be of commercial value.

RESUME.

There are few places in Washington where clays of some kind cannot be found. They are not uniform in composition or texture in the different parts of the state on account of the variation in the character of the material from which they have been formed.

The clays in the southeastern part of the state throughout the basaltic area are high in iron and are suited only for the cheaper grades of clay products. At Clayton, in Stevens county, good pottery, terra cotta, and brick clays occur. The brick clays which occur at Clayton are white, light yellow, and dark yellow in color and by using these different clays, or mixtures of them in different proportions, bricks of various colors from white to deep red with all shades between may be produced. South of Spokane at Chester, Mica, and Freeman are fire, sewer pipe, and common brick clays.

In western Washington good clays are known to occur at many different places. Brick, sewer pipe, and fire clays occur at Taylor and Kummer. Good paving brick clays are worked at Renton. Sewer-pipe clays occur at Little Falls, pottery clay on Green river a short distance below Kummer, and the clays from which common building brick may be made are very widely distributed over this part of the state.

The deposits in each of these localities are extensive, and the amount of good clay is large. The deposits will be considered in detail in the chapters which follow.

Methods of Making Physical Tests of the Washington Clays.

The clay used in making the physical tests after being thoroughly dried was passed through a pair of rolls and ground so as to pass through a forty mesh sieve. The samples, of each clay ground, usually ran from twenty to forty pounds and from these was taken what was needed for making the physical tests.

TENSILE STRENGTH.

The tensile strength is an important property of a clay and has much to do in determining its value for certain purposes. It has a practical bearing in connection with the handling, molding, and drying of the ware.

In making the tensile strength tests of the Washington clays they were mixed with sufficient water to give to them their greatest plasticity. The clay was then thoroughly kneaded and wedged so as to render it perfectly homogeneous and free from air bubbles. A piece of this thoroughly kneaded clay, large enough to a little more than fill one of the molds used in making the briquettes, was taken and worked into approximately the shape and size of the mold. The mold was then tightly clamped around this, after which it was turned on its side on a flat surface and the clay pressed with the hand until it filled the mold completely. The clay was subjected to such pressure only as could be given to it by pressing or striking it with the palm of the hand and care was taken to have the pressure as nearly uniform in each case as possible. The excess clay was then removed with a spatula and the briquette taken from the mold and set aside to dry. To prevent the clay from sticking to it the mold was oiled each time before being filled.

The cross-section of the briquettes, when molded, was one square inch, but on account of the clay shrinking in drying each briquette had to be carefully measured before being tested. After the briquettes had been allowed to dry in the air for several days, they were placed in an ordinary Riehle tensile strength machine, and subjected to a gradually increasing tension until they broke. Pieces of soft card board were placed between the inner surfaces

of the clip jaws, which hold the briquette, and the sides of the briquette so as to prevent the clips cutting into the head of the briquette and causing it to break here instead of across its smallest cross-section. On account of the fact that it is practically impossible to mold the briquettes so that there is not more or less variation in the tensile strength, it is necessary that a number of these should be tested for each sample of clay, and in this case, with a very few exceptions, the number ranged from eight to twelve.

SHRINKAGE.

All clays shrink more or less in drying and burning. The shrinkage that occurs while the clay is drying is termed air shrinkage while that which occurs during the burning is known as fire shrinkage.

Air Shrinkage.—In making the tests for air shrinkage of the Washington clays, weighed samples of the ground clay were taken and water enough added to bring the clay to its most plastic condition. These samples were then taken and thoroughly kneaded and wedged together after which they were formed into various sized briquettes, and on these lines were drawn and the length actually measured, after which they were set aside and allowed to thoroughly dry. When they were thoroughly dry these lines were again measured, and the percentage of air shrinkage determined. In mose cases three sizes of samples were used—those having approximately the dimensions of an ordinary building brick, those that were 2x2x3½ inches, and those that were 1x1x3½ inches. The larger samples were immediately subjected to high temperatures to show how they would stand rapid drying.

Fire Shrinkage.—In making the tests for fire shrinkage the two sets of small samples that had been used in determining the air shrinkage were used. These were placed in a muffle furnace and thoroughly burned at the fusing point of cone .010 or at a temperature of about 950 deg. C. after which they were measured again. They were then taken and heated to the fusing point of cone .05 (1,050 deg. C.) and remeasured. Those that had not vitrified at these temperatures were again heated

this time to the fusing point of cone .01 (1,130 deg. C.) and then measured, and the total amount of shrinkage determined from these. The difference between the total shrinkage and the air shrinkage is given as fire shrinkage. In this case the fire shrinkage is computed on the length of the freshly molded briquette and not on its length after air drying. The sum of the air and fire shrinkage, as given here, would represent the total shrinkage as compared with the length of the freshly molded briquettes, while the actual fire shrinkage is higher than shown here, if computed on the length of the air dried samples.

PLASTICITY.

The only way by which the plasticity of the Washington clays was determined was by taking a sample of the clay, and adding water sufficient to bring about a condition in the clay that would allow of it being worked into various forms or molded most readily by the hands. When a clay is spoken of as being very fat, or plastic, it means that it can be very readily formed into any shape desired and also that it retains this shape well, while the lean clay is not easily molded, as it has poor bonding power as a general thing.

The amount of water required to bring about the most plastic condition of any particular clay was determined by taking a weighed sample of the clay, and adding a measured amount of distilled water, and determining the weight of the water used, and calculating what per cent. this was of the weight of the sample of clay taken.

FUSIBILITY.

The fusibility tests were made in an ordinary muffle furnace, and Segar cones used as tests to show about what the temperature was at the time of fusing, or at the time when any particular result was obtained. The results given do not mean necessarily that a clay fused at the exact temperature found opposite a particular cone given in Part I. of this report, but rather that the clay acted in a certain way when a particular cone fused. The value of this is in the fact that when the same result is obtained on the cone again the clay should be affected

in the same way, even though the temperature may be different on account of the conditions in the kiln being somewhat different. The samples used in making these tests were molded into cones the same shape and size as the test cones, and all placed in the furnace under as nearly the same conditions as possible. It was not possible with the facilities at hand to fuse some of the samples so a few of the most refactory ones were sent to Prof. Edward Orton, Jr., Columbus, Ohio, who made fusion tests on them and the description given here of the manner of making these tests was furnished by him.

The samples were ground to pass a 40 mesh sieve. From these powders, small triangular pryamids or cones were made, dried and calcined at a low temperature. The calcined cones were then placed in small circular discs of plastic clay of a highly refractory nature. The cones were placed in circular order, and with them other standard cones of the same size, representing our usual high temperature mixtures. The positions of the test cone and the standard cones were marked on the clay pat, and also recorded by drawings, so that identification would be easy on removal from the kiln.

The furnace in which these tests were run is a gas fired cylinder, 5 in. internal diameter, supplied with an air blast from a Root blower. Air and gas are introduced into the furnace from two burners set opposite to each other, each burner producing a powerful blow pipe flame. The support on which the crucible containing the clay trial is placed, stands in the middle of the bottom of the furnace, and the blow-pipe flames, on either side strike this support, play around it, and rising upward pass through the furnace. The crucible containing the standard and test cones, stands on top of the support a few inches above the level of the blow-pipe flames, where its temperature can be increased more gradually. The time occupied in fusing a high temperature cone, runs from half to one hour, or for a very high number, two hours or more.

CHAPTER XII.

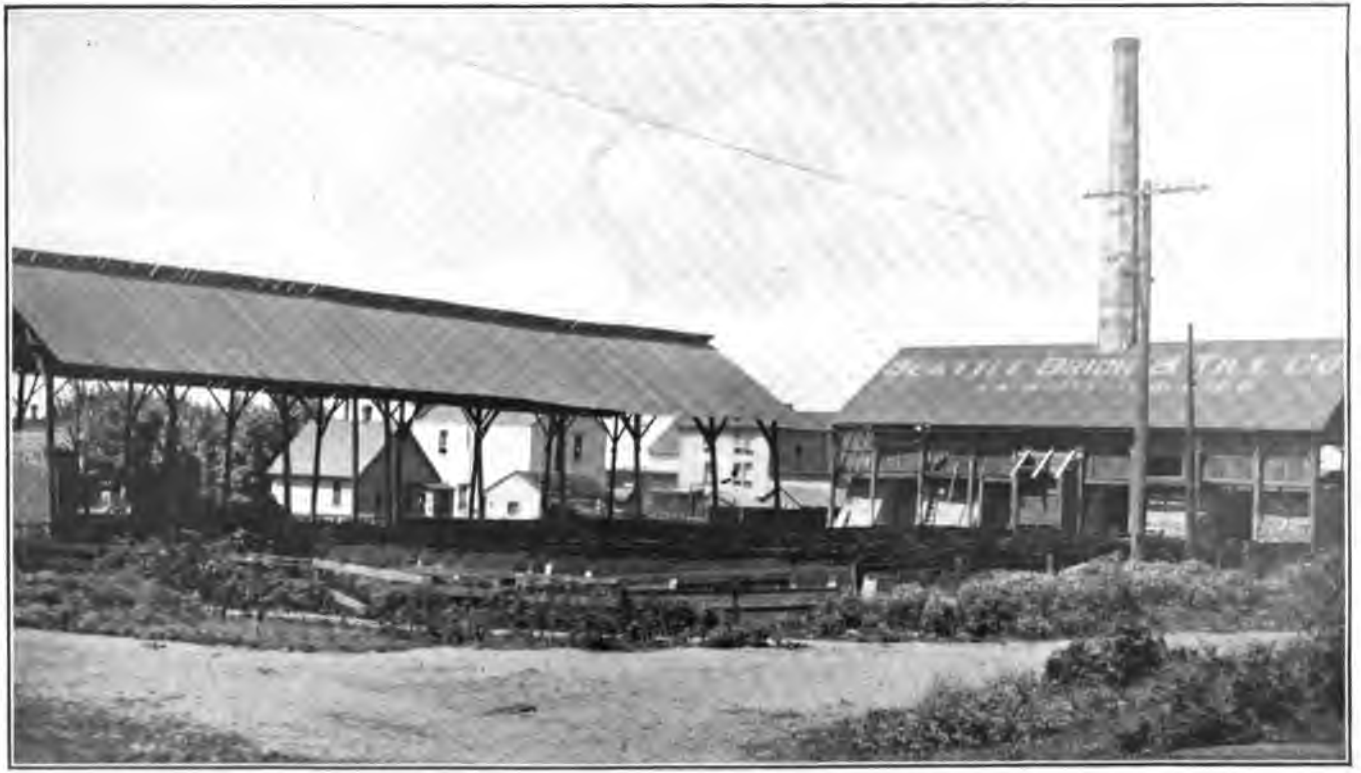
CLAYS AND CLAY INDUSTRY OF EASTERN WASHINGTON.

There are very few places in eastern Washington where clays suited to the manufacture of some kind of clay products may not be found, and in several places clays of a very good quality occur. The clay industry in eastern Washington, however, is only in its infancy. True, there are a number of places where the clays are being worked, but in most instances they are not being worked very extensively, and only a small amount of manufactured material is being produced. Then again there are probably other places throughout this part of the state where clays of very good quality occur which are not being worked at all at the present time. As the population of the state increases and as the cities and towns keep growing the demand for clay products constantly increases, and eventually these deposits will be utilized.

Spokane County.

Clay deposits of various kinds occur in many places in Spokane county. In the northern part of the county are light colored, almost white clays that have been formed from the decomposition of the granites which occur in that locality. These clays are very extensive, and cover a large area here and to the north in Stevens county. They are not being worked in Spokane county, but just across the line in Stevens county these deposits are being extensively worked at the present time. A few miles north of Spokane, at Mead, are clays of an entirely different character that are being used in the manufacture of brick. In the southwestern part of the city of Spokane are extensive clay deposits from which common brick, at least, may be made.

At a number of places in the southern part of the county



S. Shadd, Photo BRICK YARD OF SEATTLE BRICK AND TILE COMPANY, SEATTLE

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clays of various kinds are found. A few miles east of Chester are residual clays formed from gneisses and rocks of this character. At Mica and Freeman deposits of the same character are found. At Freeman, Rockford and Cheney residual clays occur that have been formed by the decomposition of basalt. At many other places in the county, clays suitable for the manufacture of the common grades of clay ware may be found, but at present they are not being utilized.

SPOKANE.

Spokane is situated about the center of the county of the same name, and is the most important town not only of the county, but of all eastern Washington, and is a very large consumer of all grades of clay building material. At the present time (1909) there are, however, only two yards for the manufacture of clay products, being operated in the immediate vicinity of that city.

A. T. Dishman Brick Yard.—The A. T. Dishman brick yard is situated in the southwest part of the city of Spokane. The material which is being used at this plant is light gray in color and is hard and shale-like in character. The deposits are very extensive extending for several miles across the county. Mr. Dishman owns twenty-three acres of land here and a considerable part of it is covered with this shale. The country rock through this part of the state is basalt, while the shale is of sedimentary origin.

In the vicinity of Spokane are large deposits of sand, gravel, and boulders. These are especially well shown along Hangman and Lake creeks between Spokane and Marshall. Along these streams in places the deposits are exposed to a depth of as much as 75 to 100 feet. This is all transported material, and has been deposited in gorges which had been formed by the streams. After the deposition of this material in these canyons the conditions changed somewhat, and the streams began cutting down into these deposits. In places, however, they have not removed all of it, but have cut into it deeply and left it exposed along bluffs high above the present stream.

The material being used at the Dishman brickyard appears to lie below this sand and gravel and between it and the basalt. The material varies considerably in different parts of the deposits, sometimes being very sandy and of no value by itself for the manufacture of clay wares. Usually more or less of this sandy material is mixed with the clay and a better grade of brick is made in this way than by using the shale alone.

Laboratory Examination.—The samples examined in the laboratory show that in the main it is a very fine grained material and has very little grit in it. Disseminated through it are many minute flakes of white mica. It has none of the odor so common to clays, and little of the slick feel that is found in many of them, especially those used for the better grades of clay products. It absorbs water rapidly and becomes saturated, but does not break up, or slake readily, in fact, hardly at all.

Under the microscope, fine grains of quartz, flakes of white mica, and a very few particles of feldspar are easily recognized. There are also present crystals of zircon along with some other substance that cannot be recognized. The shale also contains in considerable amount the skeletons of diatoms, which is a very interesting thing in connection with these deposits, as it gives us a clue to the origin of them, and the conditions that must have prevailed at the time when they were forming.

Diatoms are minute siliceous plants which live either in fresh or salt water, and the deposits formed from the accumulation of their remains may be found either in the sites of lakes or on the sea floor. The large deposits of shale, sand, and gravel which are so common throughout the Spokane valley were probably deposited in a lake which covered this part of the country at one time. The extent of this body of water has not been determined, but it probably covered a considerable area, as these gravels are known to be very widely distributed in this locality.

During Tertiary times the immense laval flows occurred throughout this part of Washington, after which lakes were formed in certain parts of the state. In these were deposited

sediments of various kinds, and finally the basins were filled and drained. This locality around Spokane represents one of these lakes of Quaternary times.

These shales, when finely pulverized, have a fair degree of plasticity, but require careful drying to prevent cracking and warping of the brick made from them. When this clay is burned at the fusing point of cone .01 (1,130 deg. C.) it is light red in color, has a good ring when struck with a hammer and has a fair degree of hardness. It begins fusing at cone 10 (1,330 deg. C.) and complete fusion takes place at cone 14 (1,410 deg. C.) When completely vitrified it has a grayish color. It requires 40 per cent. of water to bring it to its most plastic condition, shrinks 5 per cent. in drying and 8.33 per cent. in burning, or a total shrinkage of 13.33 per cent. It has a minimum tensile strength of 29 pounds to the square inch, a maximum of 70 pounds, while the average is 50 pounds.

The following chemical analysis shows the composition of this clay.

ANALYSIS OF CLAY FROM HANGMAN CREEK, SPOKANE COUNTY.
W. R. BLOOR, Analyst.

Silica (SiO_2)	59.59
Alumina (Al_2O_3)	18.98
Iron (Fe_2O_3)	4.69
Lime (CaO)	.88
Magnesia (MgO)	1.14
Potash (K_2O)	3.10
Soda (Na_2O)	0.34
Titanium (TiO_2)	0.65
Moisture (H_2O)	2.20
Loss on ignition	8.94
Total	100.46
Total fluxes	10.75

The above analysis shows this clay to contain almost exactly the average amount of silica found in the common brick clays while the amount of iron and alumina are each of them below the average of these substances in clays of this class. (See page 33. No single fluxing substance is especially high and the total is about an average of that found in clays used in the manufacture of common building brick.

Description of the Plant.—The deposits are worked by being first plowed, and in this way loosened, after which the material is loaded onto wheeled scrapers and taken to the plant. The material is all so hard that it must be ground before it can be used for brick After coming from the bank it is fed into a dry pan, and finely pulverized, after which it is carried by means of a belt conveyor to a pug mill, and thoroughly tempered. The plant is supplied with one automatic rotary wire cut auger stiff mud brick machine, with a capacity of 50,000 brick a day. There is also a pair of rolls for pulverizing the shale. These are not used very much, however, as it has been found that the dry pan is more satisfactory than the rolls. The dry pan is a large nine-foot one and will pulverize the shale as fast as needed by the brick machine.

The brick are all dried in the open air on boards or "pallets." The clay works well, and when the brick come from the machine they are very smooth and regular. There is a three-story building 160 feet long and 74 feet wide, the ground floor of which is to be used for a continuous kiln to have a capacity of 25,000 brick a day. The upper floors of this building are to be used as dry rooms, the intention being to stack the brick on these floors and utilize the heat from the kiln below. At the present time the brick are all burned in what are known as permanent wall, clasp kilns. There are three of thes kilns, each having a capacity of 500,000 brick. The power for driving the machinery is furnished by a 75 horse power Westinghouse electric motor.

Only common building brick are made here, and these are used in Spokane where they are all hauled by teams from the yard to the different parts of the city.

Six miles north of Spokane on the farm of Mr. W. G. Lake is a deposit of clay that is said to cover at least 30 or 40 acres, and is from 6 to 10 feet in thickness. The deposit is plainly stratified, showing that it has been formed in water. The different layers vary somewhat in composition, some being more sandy than others.

Laboratory Examination.—This clay as a whole has a light cream color. Some of the layers are almost white while others are distinctly yellowish in color. It absorbs water and slakes very quickly separating into a mass of very thin flakes. It has a very fair degree of plasticity, and is easily worked, but has very little of that smooth feel found in many of the best clays. It required 27.5 per cent. of water to temper it to its most plastic condition; it shrank 6.66 per cent. in drying, and when heated to the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of 1 per cent. At this temperature, however, it had not vitrified, but was still soft and light red in color. After heating to the fusing point of cone .05 (1,050 deg. C.) it had the hardness of steel, was dark brick red in color and had a good metallic ring. On being heated to the fusing point of cone .01 (1,130 deg. C.) it showed a total air and fire shrinkage of 16.66 per cent. At this temperature it did not lose its shape. Its color changed, however, to a dark gray with a slight tinge of red.

Only small briquettes of this clay were used in making tests, but these showed no signs of warping or cracking either in drying or burning. This clay fused at cone 14 (1,410 deg. C.) and after fusion had a light gray color. The tests showed it to have a minimum tensile strength of 128 pounds to the square inch.

The following analysis shows the chemical composition of this clay:

ANALYSIS OF CLAY, W. G. LAKE'S FARM, SPOKANE COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	67.16
Alumina (Al_2O_3)	19.26
Iron (Fe_2O_3)	3.26
Lime (CaO)	0.47
Magnesia (MgO)	1.13
Alkalies (K_2O, Na_2O)	1.68
Moisture (H_2O)	1.76
Loss on ignition	5.32
Total	99.99
Total fluxes	6.46

The above analysis shows this clay to be a little high in silica, with the amount of total fluxes low. The amount of iron which it contains, while low, is still large enough to give to the burned ware a good, red color.

It is almost free from grit, and the particles that do occur are extremely small. When examined under the microscope, it is found to be made up of grains that range in diameter from .1 of a mm. to .01 of a mm. The greater part of this clay is made up of grains that are about .05 of a mm. in diameter. The larger grains are many of them more or less rounded, and have a yellowish color. The smaller ones are more angular and usually clear and colorless. This clay contains a considerable number of diatom skeletons and spicules. The minerals recognized were quartz, feldspar, white mica, and occasional crystals of zircon.

MEAD.

Mead is about ten miles northeast from Spokane on the Great Northern Railway. Peone creek passes through the town and along this are deposits of clay which are being used in the manufacture of common and red repress brick. These deposits are stratified and are used to a depth of about twenty feet. The different strata vary more or less as regards the character of the material, in some places being very sandy. The different layers, however, are mixed in the manufacture of brick. The clay is of a light yelowish color and fine grained. Disseminated through it is a considerable amount of very fine scales of white mica. There are also some small particles of black sand scattered through it.

J. T. Davie Brick Co.—This company operates a brick yard near Mead on the north bank of Peone creek. A composite sample of this clay such as is used by this company in the manufacture of brick was tested in the laboratory. It had a fair degree of plasticity and required 23 per cent. of water to temper it so that it had its greatest degree of plasticity. It shrank 5 per cent. in drying and 5 per cent. additional in burning, making a total shrinkage of 10 per cent. It did not crack in either drying or burning and should stand rapid drying.

After burning at the fusing point of cone .01 (1,130 deg. C.) it had a dark red color, was almost steel hard, and had a clear metallic ring. Cones made from this clay began to soften at the fusing point of cone 4 (1,270 deg. C.)

The following chemical analysis shows the composition of this composite sample:

ANALYSIS OF CLAY FROM MEAD, SPOKANE COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	60.58
Alumina (Al_2O_3)	16.15
Iron (Fe_2O_3)	6 28
Lime (CaO)	2.60
Magnesia (MgO)	1.98
Potash (K_2O)	3.23
Soda (Na_2O)	1.06
Titanium (TiO_2)	0.57
Moisture (H_2O)	1.36
Loss on ignition	5.76
Total	99.49
Total fluxes	15.56

The foregoing analysis shows this sample to be above the average, in the amount of total fluxing substances, of clays used in the manufacture of common brick while the amount of alumina is lower than the average. The amount of silica, however, is just about the average. (See page 33).

CHESTER.

This is a station on the Oregon Railroad and Navigation Company's line between Portland and Spokane. It is about six miles east and three miles south of Spokane, and is on the southern edge of the gravel deposits which occur throughout the Spokane valley. To the east, south, and west of it are low hills which are composed of metamorphic rocks that are mainly gneisses and schists.

Bergman Clay Manufacturing Company.—The plant owned and operated by this company is located at Chester. The clays, however, that are being used by the company do not occur at Chester, but are situated about two and one-half miles east of there, and are loaded on wagons and hauled by teams to the plant.

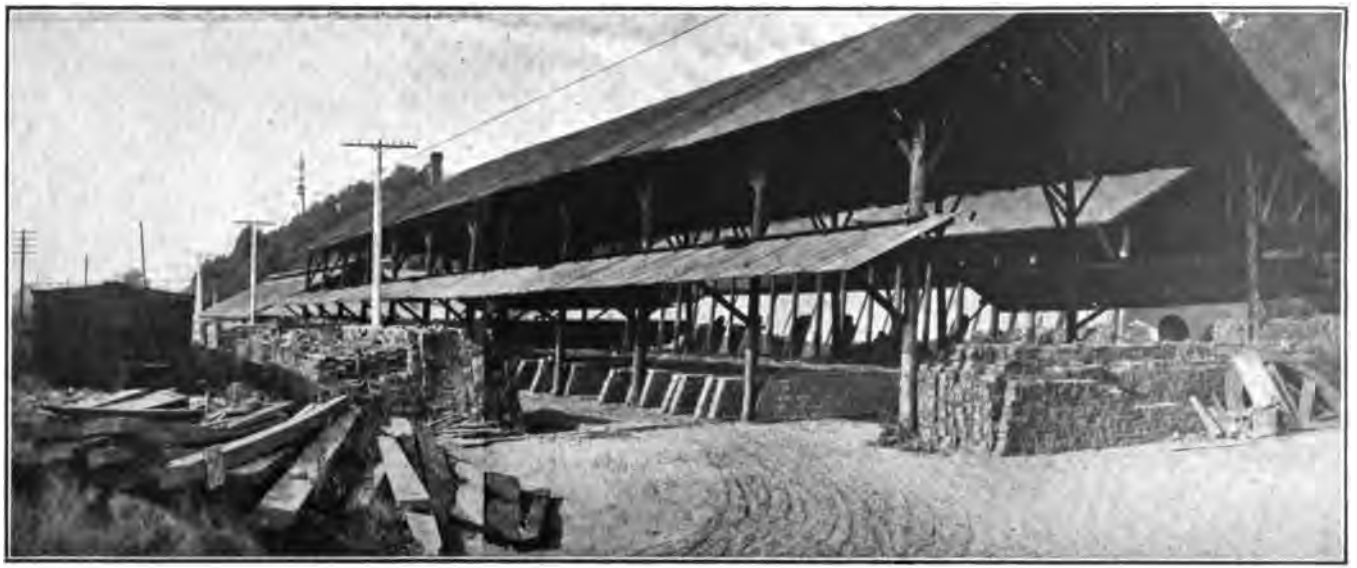
In the main the clays are residual deposits that have been formed by the decomposition of the country rock in that locality. These rocks are schists, gneisses and very coarse granites which contain a considerable amount of feldspar, quartz, and mica,

these different minerals having been segregated more or less, so that in places quite large veins of feldspar occur with very little of any other minerals, while in other places it is largely quartz, and in still others it may be almost all mica and occurs as mica schist.

In many places these rocks have decomposed, and formed beds of clay of considerable thickness and varying composition, on account of the great variation in the composition of the rocks from which they have been derived. In some places the clays are typical residual deposits, while in others they have been transported short distances and then deposited and are plainly stratified, the different layers showing very distinctly. In places in the stratified deposits fossil leaves are quite plentiful. These are of comparatively recent date as they are found to belong to trees that are living in the locality at the present time. In other places they are not really typical residual or sedimentary clays, but rather somewhat of a mixture of the two. The deposits occur over a large area in this locality, but on account of the variation in character only in places are they of any commercial value. In certain parts of these deposits layers of limonite occur that are as much as two or three inches thick. These in some cases extend for quite a distance as continuous layers, while in other cases the iron occurs more in the form of masses and nodules. On account of this iron the clay found in this locality is of various colors, in some cases being a deep red, in others a light yellow and various shades of red and yellow, as the amount or condition of the iron varies, while in places it is almost white.

These deposits are worked by means of open cuts, the clay being dug with picks and shovels, loaded into wagons and hauled by teams to Chester. There is as a general thing but little material above the clay, so that the amount of stripping to be done is small.

Laboratory Examination.—The Bergman Clay Manufacturing Co. is using three different grades of clay from this locality. One of these is a light yellow in color, one almost a pure white, while the other is a very light gray.



S. Shedd, Photo BRICK YARD OF BUILDERS' BRICK COMPANY, SEATTLE

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The light yellow clay is more or less streaked as it comes from the bank, it being a mixture of yellow and white. There is enough of the yellow present, however, so that when the clay is finely pulverized the whole of it appears light yellow in color. This clay is coarse grained, and contains a considerable amount of quartz grains disseminated through it. Many of these grains are of good size and are easily recognized in the clay before it has been pulverized. This clay, when dry, is hard, and while it absorbs water readily, it does not slake or fall to pieces. It does, however, become much softer, and is very easily broken to pieces when thoroughly saturated. On account of the large amount of sand that this clay contains it has but little plasticity. There is enough, however, so that it may be molded into brick, and with careful handling there should not be an excessive amount of loss on account of breakage. When formed into small briquettes and tested it showed the following results: The minimum tensile strength per square inch was 18 pounds; the maximum 33 pounds; while the average was 26 pounds. It required 25 per cent. of water to bring it to its most plastic condition.

The sandy nature of this clay causes it to shrink but little in drying and burning. The amount of air shrinkage in drying was only 3.33 per cent. while there was no additional shrinkage when heated to the fusing point of cone .01 (1,130 deg. C.) At this temperature, however, it did not vitrify, and was hardened but very little, if any. At very low temperatures this clay changes from a yellow color to a light bright red. At cone .01 (1,130 deg. C.) it is light colored but does not have so much of a red color while at cone 14 (1,410 deg. C.) the red is practically all gone and it has a dirty brownish color. At this temperature it has hardened somewhat, but has not completely fused.

When viewed under the microscope the grains of the different minerals of which it is composed are seen to be, in most cases at least, coated with a very thin layer of iron oxide, probably limonite. The individual grains vary much in size and range from those that require very high powers to distinguish, to those

that may be easily recognized by an ordinary pocket lens. In this clay the grains are all well rounded. They show no well marked peculiarities, and the different minerals are not easily recognized. It contains, however, quartz, feldspar, an occasional flake of muscovite, small particles of iron oxide, and a very few minute crystals of zircon. The chemical analysis shows the presence of a little titanium, but no crystals of rutile were recognized microscopically.

The white clay is very uniform in color as it occurs at this place. It is a hard clay which absorbs water readily, but does not slake very much, and does not even soften. It is a clay that has been only partially formed. That is, the rock has not been completely decomposed. It has but little of the smooth greasy feel so common to the better grades of clay. The chemical analysis shows it to contain a rather large amount of silica, an average amount of alumina, and to be very low in fluxing substances such as iron, lime and the alkalies. In hand specimens quartz appears to be a very prominent constituent. There are also large numbers of minute scales of white mica disseminated throughout the mass.

When pulverized the clay has the appearance of being very sandy, and is not very plastic. It has enough plasticity, however, so that it may be molded into bricks, and when dry is hard enough so that it may be handled without serious loss from breaking. When tested for tensile strength it showed the following results: The maximum tensile strength was 54 pounds per square inch, the minimum 45 pounds, while the average was 50 pounds. It required 20 per cent. of water to make it into its most plastic condition.

On account of its sandy nature the amounts of air and fire shrinkage are small. The shrinkage in drying was 5 per cent. and when heated to the fusing point of cone .01 (1,130 deg. C.) there was no additional shrinkage. At this temperature it did not vitrify, and was hardened but very little. Its color after heating to this temperature was white, and in fact whiter than before being heated. At the fusing point of cone 14 (1,410 deg. C.) it has apparently undergone but very little additional change.

It has the same color that it has at cone .01, and has hardened but little if any more. When struck it had a hollow sound instead of a clear ring.

This clay when studied under the microscope is shown to be a mass of various sized irregular shaped grains. The largest of these grains have a diameter of as much as .25 mm., while the smallest ones are not more than .001 mm. in diameter. The grains are practically all very angular and sharp cornered, and show no sign of having been ground together in being transported by water. The minerals recognized were quartz, feldspar, some muscovite and sericite in very small flakes, and an occasional zircon.

The grayish colored clay used by this company is very fine grained, uniform in color, and is very fat and plastic. It absorbs water very rapidly and slakes readily, breaking up into small thin flakes. It has a very smooth greasy feel. The only mineral that can be distinguished with the naked eye is very minute scales of white mica, which occur disseminated throughout the mass. The chemical analysis shows this clay to be much lower in silica than either of the others from this same locality, while the amount of the alumina is considerably higher. The amount of the fluxing substances, as iron, lime, and alkalies, while a little higher than in the others, is still low.

This clay has a very high plasticity and is easily worked and molded into any form desired, and when dry is hard and firm. The following shows the results of the tests of tensile strength: The minimum tensile strength was 80 pounds to the square inch, the maximum 120 pounds, while the average was 90 pounds. This is considerably higher than that of either of the other clays from the same locality as shown above. It required 32.5 per cent. of water to temper it, and bring it to its most plastic condition.

This clay in drying has a shrinkage of 8.33 per cent. and while this is fairly high it shrinks without cracking even when dried rapidly. When heated to the fusing point of cone .01 (1,130 deg. C.) it shrank 6.66 per cent. additional. After heating to this temperature it was white in color, completely vit-

rified but not fused, had a good clear ring when struck, and was very hard.

The sample of this clay, studied under the microscope, was seen to be very fine grained, the largest individuals seen being not more than .03 of a mm. in diameter, and these are not common. The greater part of it consists of grains about .0015 of a mm. and less in diameter. The larger grains are slightly colored and are rounded to sub-angular in outline.

When taken between the teeth no signs whatever of any gritty substance is noticed. It has a clay odor, but no taste.

The following chemical analyses show the composition of these different clays:

ANALYSES OF CLAY, TWO AND ONE-HALF MILES EAST OF CHESTER, SPOKANE COUNTY.

W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	59.04	76.96	52.32
Alumina (Al_2O_3)	25.74	16.39	30.66
Iron (Fe_2O_3)	5.08	0.31	1.70
Lime (CaO)	0.22	0.40	0.80
Magnesia (MgO)	0.06	0.08	0.46
Potash (K_2O)	0.12	0.20	1.50
Soda (Na_2O)	trace	trace	trace
Titanium (TiO_2)	0.52	0.44	0.52
Moisture (H_2O)	0.39	0.29	1.76
Loss on ignition	8.81	5.48	10.08
Total	99.98	100.55	99.82
Total fluxes	6.00	1.43	4.98

I. Light yellow clay.
II. White clay.
III. Light gray clay.

From the above analyses it is seen that none of these clays are very high in fluxing substances, and that II. and III. especially are very low. Number III. is also very plastic and considerable amounts of either or both of the others may be mixed with it without decreasing the plasticity enough to injure the value of the clay, in fact for most purposes a mixture of these clays would be better than either one of them alone. When I. or II. is mixed with number III. the amount of shrinkage in drying and burning would be less than where number III. is used alone. In actual practice these clays are mixed in various proportions

in order to produce different colors and different grades of ware.

This company manufactures fire brick, repress facing brick, common building brick, and sewer pipe in various sizes up to 24 inches in diameter.

Description of the Plant.—The plant operated by the Bergman Clay Manufacturing Company for working these clays is not a very large one. There is one auger stiff mud machine with a capacity of 25,000 brick a day. There is one pair of rolls for pulverizing the clay. After passing through these rolls the clay goes to a pug mill where it is thoroughly mixed and tempered before going to the brick or sewer pipe machine. There are two repress machines each having a capacity of about 3,000 brick a day, and operated by hand. There is one sewer pipe machine on which various sized pipes are made, those having a diameter of 24 inches being the largest.

The main building is 60 by 100 feet and three stories high. Two of these floors are used mainly as dry rooms for drying sewer pipe, and are steam heated. The brick are mostly dried on pallets under sheds in the open air. There is one circular down draft kiln in which the sewer pipe and some of the brick are burned. Most of the brick, however, are burned in temporary square kilns. The power for driving the machinery, and the steam for heating the main building is furnished by an 80 horse power boiler and engine. The output of this company is used mainly in the city of Spokane.

MICA.

Mica is a small station on the line of the Oregon Railroad and Navigation Company, and is nine miles east and seven miles south of the central part of Spokane. It is situated on the border between the basaltic rocks and the granites, gneisses, and schists that occur east of Chester. To the south and west of Mica the country rock is basalt, while to the north and east it is granite, gneiss and schist. To the east of Mica the country is rough and hilly, the highest peak, known as Mica Peak, being 5,200 feet above sea level, or about 2,700 feet above Mica. There

is a small stream known as California creek which heads well up on Mica Peak, flows to the southwest, and passes almost through the town of Mica. For a considerable distance above the town this stream has a narrow valley along its course, and alluvial deposits have been formed.

American Fire Brick Company.—The plant and clay deposits of this company are located at Mica. There are several different grades of clay found in the deposits that are being worked by this company. As already stated, Mica is about on the contact between the basalt and the granites, gneisses, and schists which occur to the east and north of there. On account of this the clays which occur here are of two different kinds, one of which has been formed by the decomposition of the basalt, while the other has been formed by the decomposition of the metamorphic rocks. Where both of these are found in the same deposit, and are residual, the red or yellow basaltic clay occurs above the other. The thickness of the basaltic clay varies in different places, and may be only a foot or so, or it may be as much as fifteen to twenty feet, while in some places it does not occur at all. When the deposits worked by this company were visited by the writer there were about six feet of this basaltic clay exposed in the face of the workings. This clay was not being used at that time, and had to be removed in order to get the other clay. Samples of this clay were not tested, but in all probability it is of such a character that ordinary building brick, at least, might be made from it, and by mixing it in certain proportions with the light colored clays facing brick of various shades and colors might be produced.

The clays which occur at Mica are in the main residual, but in some cases under the influence of gravity and surface wash the clay has been shifted from its original position and deposited further down the slope. Where this has happened the clays may present more or less of a stratified appearance, and the deposits where they are being worked occur mainly in alternate layers of a more or less pure kaolinite and clay of a sandy micaceous nature. These do not grade into each other, but there is a sharp line of demarcation between them. The layers

occur in practically a horizontal position. The clays formed from the decomposition of the granites, gneisses, and schists vary somewhat in color on account of the variation in the composition of the rocks from which they have been formed, and range in composition from almost pure kaolin to a clayey material of low grade and of little value. In places through this locality are pegmatite dikes, and these when they decompose produce very white pure clay. The residual clay is often colored more or less by the iron which was in some of the minerals composing the granites, gneisses, and schists, while in some cases it is colored by the iron from the basalt which was above these rocks. In this case percolating water has carried it from the decomposing basalt down into the clay which was forming below.

In places these clays are almost pure white in color and are practically free from iron. Where this is the case they have probably been formed largely from the feldspar which occurs in the pegmatite dikes. Much of this clay also contains a considerable amount of muscovite in small flakes disseminated through it. The deposits are very extensive, covering a considerable area, and in places having a thickness of from twenty to thirty feet.

The particular place where these clays have been opened by the American Fire Brick Company shows several different grades of clay, only two of which, however, are used. These have been designated by this company as its fire clay and sewer pipe clay. These two clays differ somewhat in appearance and in composition.

Laboratory Examination.—Three samples of the clay from here were analyzed and tested with the following results:

One of these clays is a coarse grained clay in which there is, however, a considerable amount of very fine clay substance. There is considerable quartz sand disseminated through it, in some cases the grains being as much as one-twentieth of an inch in diameter. It has also a considerable amount of muscovite distributed through it. This clay absorbs water rapidly, but slakes slowly. It has a fair degree of plasticity and works

fairly well. On account of the amount of quartz, which it contains, and the fact that the grains on the whole are large and also the fact that it contains a large amount of mica it has only a small amount of shrinkage in drying and burning. The air shrinkage was only 5 per cent., and when heated to the fusing point of cone .01 (1,130 deg. C.) there was no additional shrinkage. At this temperature the clay had not vitrified, and had hardened but little, so that when struck, in place of having a clear ring, it had a hollow sound.

It required 19 per cent. of water to give to it the greatest amount of plasticity. It had a minimum tensile strength of 48 pounds to the square inch, a maximum of 65 pounds, while the average of the eight briquettes tested was 59 pounds per square inch.

The chemical analysis shows it to be high in silica, with about an average amount of alumina, and very low in total fluxing substances. This clay is white in color, and remains white after being burned.

The microscopic examination of samples of this clay shows that the size of the grains varies within a very wide range. There is a large amount of muscovite in this clay, the flakes of which in some cases are as much as 3 mm. in diameter. Most of them, however, are much smaller than this, the average being about .5 mm. The mica composes a very considerable part of this clay. There is some quartz in it, the individual grains of which in some cases are as much as 2 mm. in diameter. These grains are mainly subangular in outline. There is a very considerable part of this clay that is made up of minerals that are .04 mm. and less in size. On the whole, however, the clay is rather coarse grained and sandy.

The second sample from this localiy that was examined and tested is different in certain respects from the one just described. It is very light, almost white in color, is finer grained and is practically free from the large grains of quartz that are found in the first one. This clay has a rather smooth feel, and has but little grit in it. There is considerable muscovite disseminated through it in small flakes.

S. Shedd, Photo. CLAY BANK OF LOSHE BRICK COMPANY, SEATTLE

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It requires 30 per cent. of water to bring it to its most plastic condition and in air drying it shrank 5.12 per cent. while there was no additional shrinkage when heated to the fusing point of cone .010 (950 deg. C.). At this temperature, however, it was not vitrified, but at the fusing point of cone .01 (1,130 deg. C.) it had shrunk 5 per cent. in burning, or a total in drying and burning of 10.12 per cent. At the fusing point of cone .01 (1,130 deg. C.) it had vitrified, was steel hard, and had a nice clear ring. At this temperature, it had only reached the point of incipient vitrification and was not fused. Its color after having been heated to this temperature was practically the same as before. A sample of this clay tested by Prof. Edward Orton, Jr., was completely fused at cone 30.5 or about 1,740 deg. C., and is what he would consider as No. 2 refractory grade, and amply able to endure the temperature of ordinary uses such as boiler setting, pottery kilns, ovens, fire places, etc.

This clay is very plastic, and the most sticky one of all the samples tested. It has a minimum tensile strength of 62 pounds to the square inch, a maximum of 100 pounds, while the average of the ten briquettes tested was 86 pounds to the square inch. It has good bonding power and may be dried rapidly without cracking. It has a high tensile strength so that there should be but little loss from breakage.

The microscope shows this clay to be much finer grained than the other sample from this locality. The larger part of the sample examined was made up of individuals about .02 mm. and less in diameter.

The chemical analysis shows this clay to have about 20 per cent. less silica than the other one from this locality and to have about 12 per cent. more alumina. Like the other, however, it is very low in fluxes.

The other sample which is designated as No. III. in the table of chemical anlyses given below, is very much like No. II. in appearance. It is perhaps a trifle darker in color, has about the same texture, absorbs water and slakes quickly breaking into very small particles. When moistened it has a very strong clayey odor, and is very plastic. If taken between the teeth only

very small particles of gritty substances are noticeable and these are not abundant. This clay works very smoothly and dries without warping or cracking.

The analysis shows it to be about the same in silica as No. I. It is lower in alumina than this sample, while the total fluxing substances are higher than in either of the other samples. The amount, however, even in this sample is not excessive.

The following analyses show the chemical composition of these three samples:

ANALYSES OF CLAY FROM MICA, SPOKANE COUNTY.
W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	75.04	54.80	73.68
Alumina (Al_2O_3)	19.18	31.10	18.15
Iron (Fe_2O_3)	0.76	1.68	2.01
Lime (CaO)	.....	.....	.59
Magnesia (MgO)	.....	trace	1.21
Alkalies (K_2O, and Na_2O)	0.45	0.21	1.35
Titanium (TiO_2)	0.15	0.22	.....
Moisture (H_2O)	0.86	2.70	.....
Loss on ignition	4.54	9.40	8.49
Total	100.48	100.12	99.98
Total fluxes	1.36	2.12	4.06

I. Coarse grained clay.
II. Fine grained clay.
III. Fine grained grayish clay. O. A. Thomle, analyst.

From the above analyses it is plain that these clays are very refractory and would fuse only at very high temperatures. On account of this, along with certain physical properties which they possess, they are well suited for the manufacture of certain kinds of clay wares. At the present time the American Fire Brick Company is manufacturing sewer pipe of various sizes, fire brick, vitrified electric conduits, salt glazed building and mantel brick, dry and repress face brick, sidewalk tile, vitrified foundation blocks, fire proofing, and terra cotta chimney tops. By mixing the different clays found here in different proportions these various kinds of ware are produced.

This clay contains a considerable amount of free silica, and takes a good salt glaze, so that in the manufacture of all the glazed ware produced by this company the glazing is done by

the addition of salt to the kiln at the time when the burning of the ware is just about completed.

Description of the Plant.—The clay deposit is worked by open pits or surface workings. The clay is first loosened by blasting, after which most of it is loaded onto small cars which run over a track that slopes very gently toward the mill. Some of the clay that is used by this company is situated about an eighth of a mile from the plant and this is loaded onto wagons and drawn by teams to the plant. In some cases the clays are allowed to weather for a short time after being taken from the bank before they are used, while in others they are used without weathering.

The plant of the American Fire Brick Company is supplied with a nine-foot Stevens dry pan, an eight-foot Stevens wet pan, and a twelve-foot pug mill for grinding and tempering the clay. The clay after being thoroughly ground in the dry pan, is taken by means of a bucket elevator, to the upper floor of the building where it is screened and stored for use. From the storage bins the ground clay goes to the pug mill or to the wet pan where it is thoroughly tempered.

There is one auger stiff mud brick machine, with an automatic wire cutting table, which has a capacity of 50,000 brick a day. There is also one Richardson repress brick machine having a capacity of 20,000 brick every ten hours, which is used in repressing the bricks from the auger machine. In addition to the above there is one four mold Berg dry press brick machine on which the better grades of facing brick are made. One Turner, Vaugh and Taylor sewer pipe press is in use here. This has a forty-four inch stroke and twenty tons pressure. The various sizes of sewer pipe, drain tile, conduits, and walk coping are made on this press. It has a capacity of 5,000 pieces of four-inch pipe every ten hours.

There is one large building 140x160 feet and three stories high. In this building is located the various clay working machines described above, but these occupy only a small part of it and the remainder is used as a dry house for the various wares. The floor in that part of the building used as a dry house is

made of narrow boards about three-fourths of an inch apart. About twelve inches below the floor are steam pipes which heat it and dry the ware. The brick are taken from the machines by what is known as the pallet system and the pallets spread around over the floor. The brick require from five to seven days for drying. After thoroughly drying the brick are burned in circular down draft kilns of which there are four. These are from twenty to thirty feet in diameter and are substantially built.

The power plant consists of a 125 horse power Buckeye rapid motion engine and two 80 horse power boilers. These boilers, in addition to furnishing steam for the engines supply heat for drying the ware.

This plant was erected in 1903 and has been in operation since that time.

FREEMAN.

This is a little town on the Oregon Railroad and Navigation Company's line about two miles south and a little east of Mica. It is about fourteen miles in a straight line south-east from the center of Spokane. Like Mica, Freeman is situated just about on the dividing line between the basaltic area which lies to the south and west and that of the granites, gneisses, and schists which occur to the northeast. On account of this the clays that occur here are of two general kinds as far as the character of the rock from which they have been formed is concerned, that is those formed by the decomposition of the gneisses and schists, and those formed by decomposition of the basalt. These clays are mainly, at least, residuary deposits. In some cases they may have been shifted somewhat by gravity and surface wash, but where the deposits are being worked they are mainly residual. These deposits are very extensive in this locality covering a large area and having, in many places at least, a great thickness. The clays which have been formed from the decomposition of the gneisses and schists are known to have a thickness in some cases of from seventy-five to one hundred feet, while the basaltic clays are known to be as much as fifty feet in some places.

The granites, schists, and gneisses in this region frequently contain dikes, or veins, composed in some cases of almost pure

feldspar, while in others they are made up of quartz and feldspar. These veins vary in size from only an inch or two in width to as much as two or three feet in width. When these decompose, especially those composed of feldspar, almost pure kaolin is formed. When those that contain quartz in addition to this feldspar are decomposed, the clay is more or less sandy, but on account of the absence of the ferro-magnesian minerals it contains little or no iron, and hence is white in color. In some places in these deposits there is a considerable amount of very pure clay that has been derived from these veins and dikes. At the present time, however, the different grades of clay which occur in the bank are not separated, but are all mixed together and used in that way, except in the case of a small amount that is used for the manufacture of fire brick.

There are, in the clays which occur here, many shades and colors, the principal ones being reds, yellows, browns, and whites. The various shades of red and yellow are due mainly to variation in the amount and condition of the iron which occurs in the clay. At a number of places in this locality the clays which have been formed from the decomposing granitic rocks have been exposed to a depth of twenty-five to thirty feet, and in these places the deposits show very plainly that they are residuary, and that they have suffered no displacement as a result of weathering. They occupy the same position that the rocks did from which they have been formed. In many places they still show the structure of the rocks, but are soft and incoherent. The veins of feldspar or feldspar and quartz, in many instances are well marked, and as distinct as they are in the rocks, the only difference being that they have changed to kaolin and sand.

These rocks have been profoundly affected by weathering, but on account of the country being comparatively level in this particular locality, the amount of erosion has not been very great, so that we find the rocks have decomposed and softened in places to depths of from seventy-five to one hundred feet.

Washington Brick, Lime and Manufacturing Company.— This company is the only one working the clay deposits found around Freeman, and it is using both the basaltic clay and that

formed from the gneisses and schists. The two are mixed in certain proportions in the manufacture of common brick.

The clay formed from the gneiss and schist has been opened up in a number of different places by the company, but is being worked mainly in one place where there is a large open pit with a vertical face of about twenty-five feet. The clay exposed in the face of the pit varies a great deal in composition and the occurrence of any one grade is irregular. The surface soil and clay is largely from decomposing basalt. This layer varies much in thickness, in some cases being only a foot or so while in others it is a much as ten feet. The different grades of clay which occur in this pit are not separated as they are used only to mix with the basaltic clay.

This clay is of a sandy nature, has very little plasticity, and a low tensile strength. It would have a small amount of shrinkage in drying and burning.

The deposit is worked by means of a surface pit, the clay being loosened by the use of powder, after which it is loaded on tram cars and taken to the mill, which is about one hundred yards south of the clay bank.

The fire clay used by this company comes from these granitic clays, and is obtained by carefully selecting a certain grade of clay from these deposits. The fire clay is very irregular in occurrence, and the amount of it small as compared with the amount of the other clay.

The basaltic clays which occur in this locality have been opened up just to the south of this company's buildings. These deposits at this place have a thickness of about sixty feet, but are worked to a depth of only about thirty feet. This is a residual clay that has been formed from the decomposition of the basalt or at least the greater part of it is. A little of the upper part of it may have been shifted about somewhat by the action of the wind, and some of the granitic clay mixed with it.

Laboratory Examination.—This clay is of a deep reddish brown color, the deposit being in the main very uniform, not only in color, but also in texture and composition. There are some places, however, where it does have a slightly sandy nature,

but most of it is quite free from sand and grit. It has very little of the slick feel common to the better grades of clay. It absorbs water rapidly, and slakes quickly, breaking up into fine particles.

It has a fair degree of plasticity, but if used by itself would require careful drying and burning to prevent cracking and warping. It requires 23 per cent. of water to bring it to its most plastic condition, shrinks 6.66 per cent. in drying, and when heated to the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 3.33 per cent. and was completely vitrified. After having been burned at this temperature it was a very dark red, and while completely vitrified, it was not fused, and retained its shape perfectly. It was completely fused at the melting point of cone 6 (1,250 deg. C.) and then it has a very slight greenish tinge.

This clay showed a minimum tensile strength of 134 pounds to the square inch, a maximum of 168 pounds, with an average for the 12 briquettes tested of 146 pounds to the square inch. This is a high tensile strength, and there should be a very small amount of loss due to breakage in the handling of the dried ware.

The following analyses show the chemical composition of these clays:

ANALYSES OF CLAYS FROM FREEMAN, SPOKANE COUNTY.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	65.96	59.92	61.72
Alumina (Al_2O_3)	18.28	16.65	18.53
Iron (Fe_2O_3)	4.80	8.25	2.01
Lime (CaO)	1.51	2.22	3.82
Magnesia (MgO)	0.72	3.71	1.47
Potash (K_2O)	3.52	2.14	2.19
Soda (Na_2O)		2.02	2.01
Moisture (H_2O)	1.70	.....	.....
Loss on ignition	3.44	5.19	8.31
Total	99.98	100.10	100.06
Total fluxes	10.55	18.34	11.50

I. Basaltic clay. W. R. Bloor, analyst.
II. Basaltic clay. A. A. Hammer, analyst.
III. Granite clay. A. A. Hammer, analyst.

From the above analyses it is seen that the amount of fluxing substances in these clays is above the average, while the amount

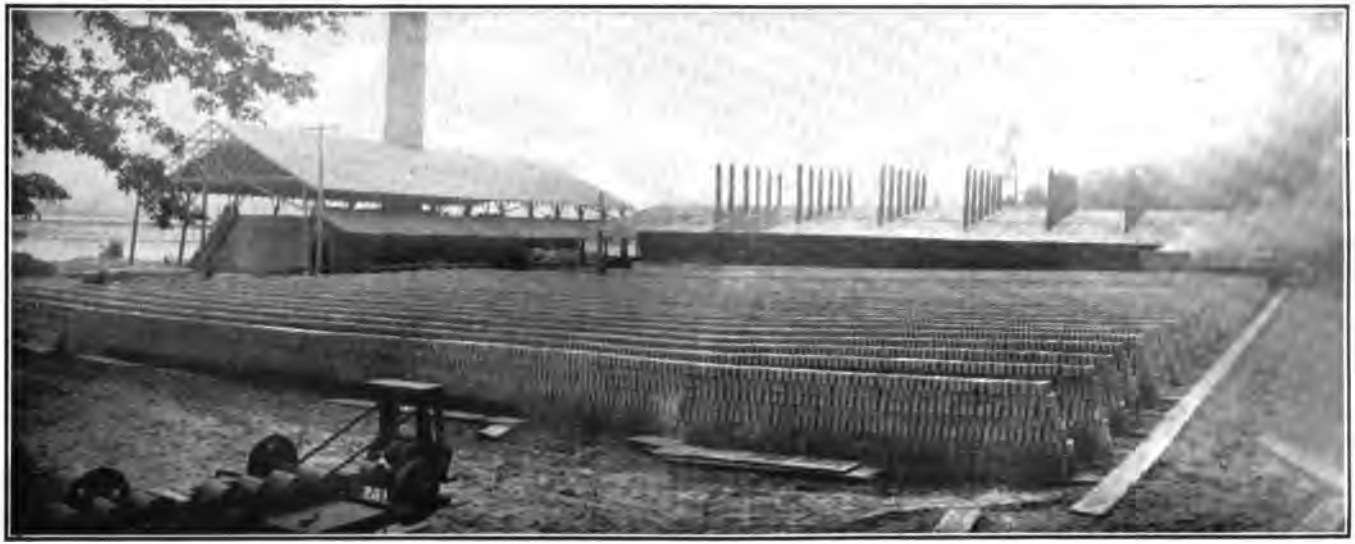
of silica and alumina is not far from the average for ordinary brick clays. (See page 33.) The amount of iron in the basaltic clay is high and in No. I. especially is above the average of clays that are being used even for ordinary building brick. The sample of granitic clay analyzed is representative of the better grades of clay from this locality. The analysis shows that it has considerable less iron than either of the samples of the basaltic clay that were analyzed, and the amount of silica is between the amounts shown in these samples. The amount of lime and magnesia in this sample is large as is also the alkalies. The total of the fluxing substances is so great that this clay will not withstand very high temperatures.

The following chemical analysis shows the composition of a fresh undecomposed sample of the basalt from which the basaltic clays around Freeman have been formed:

ANALYSIS OF BASALT FROM FREEMAN, SPOKANE COUNTY.
O. A. THOMLE, Analyst.

Silica (SiO_2)	57.47
Alumina (Al_2O_3)	13.86
Iron (Fe_2O_3)	6.29
Lime (CaO)	7.42
Magnesia (MgO)	4.27
Potash (K_2O)	0.42
Soda (Na_2O)	3.85
Manganese (MnO)	0.11
Titanium (TiO_2)	0.75
Moisture (H_2O)	0.36
Total	99.81

A comparison of these results with those obtained from analyses of the basaltic clays from Freeman shows that the basalt has a little less silica than has the clay, the amount of alumina is about the same, while the lime and magnesia are much more abundant in the basalt than they are in the clays, and the alkalies are about the same in each case. These results are not quite what one would expect if the clay had been derived wholly from the decay of basaltic rock. The general tendency of a basalt when decomposed is for the product to contain a less percentage of practically all of its constituents except alumina. From the above it would appear that perhaps this clay, or at least a part of it, has been shifted somewhat and perhaps mixed with some of the clay from the granitic rocks. In places it con-



S. Shedd, Photo. YARD OF LOSHE BRICK COMPANY, SEATTLE

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tains considerable amounts of mica in very small particles which would also tend to prove this.

In the manufacture of common building brick the Washington Brick, Lime and Manufacturing Company uses a mixture of the granitic and the basaltic clays, and much better results are obtained in this way than by using either one alone. The basaltic clay is plastic, but is liable to warp and crack in drying and burning when used alone. This tendency is overcome by mixing some of the more sandy granitic clay with it. The amount of shrinkage is also reduced, and the clay is made more refractory.

Under the microscope most of the larger grains of the basaltic clay in reflected light appear yellow in color. There are some of these larger grains that are as much as .2 mm. in diameter, but the greater part of the sample examined was composed of grains that were .02 mm. and less in diameter. The larger grains are many of them well rounded, while others are sub-angular, and the smaller ones are practically all sharp cornered and irregular in outline.

The minerals recognized were quartz, feldspar, mica, zircon, and apetite. There are also occasional rounded grains about 2 mm. in diameter of limonite distributed through the sample examined.

Description of the Plant.—The plant located at Freeman is operated entirely for the manufacture of common building brick. At one time fire brick also were made here, but at the present time fire clay is shipped from here to the plant at Clayton and the fire brick made there. The plant at Freeman has one auger stiff mud brick machine with a capacity of 30,000 brick a day, one repress machine for common repress brick, and for fire brick, also one dry press machine. This, however, is not used very much as the principal thing manufactured here is the ordinary red building brick. The plant is also supplied with rolls for pulverizing the clay, a pug mill for tempering it, and a wire cutting table, this being operated by hand.

The brick are taken from the brick machine, stacked on small steel cars, and run directly into the steam heated tunnel driers. There are six of these driers, each of which has a capacity of

166,666 brick or a total dry kiln capacity of 1,000,000 brick. These dry kilns have a temperature of 120 deg. F. at the cooler end where the cars loaded with the green brick enter them, while at the other where the dried brick are taken out they have a temperature of 180 deg. F. and as the cars gradually move from one end of the kiln to the other they are gradually subjected to higher and higher temperatures, until they are thoroughly dried. It usually requires about forty-eight hours to dry the brick ready for burning, but the dry kilns are so arranged that they may be heated to a higher temperature, and the drying completed in twenty-four hours.

The bricks are burned in up draft rectangular kilns, with the exception of the fire brick, which are burned in a down draft bee hive kiln having a capacity of 50,000 brick. This kiln, however, is no longer in use. The common building brick require from eleven to fourteen days for burning, are hard, and have a good red color.

The machinery is driven by steam, and the dry kilns are steam heated.

CHENEY.

Cheney is a small town in the southwestern part of Spokane county, and is twelve miles south and six miles west of the city of Spokane. It is on the main line of the Northern Pacific Railway. The Washington Central Railroad also branches off from the main line of the Northern Pacific at this point. The country rock here is all basalt. This has decomposed, and in places formed beds of residuary clays which have been used for the manufacture of ordinary building brick. These deposits have a wide distribution throughout this locality. One sample was taken from here and tested and analyzed.

Laboratory Examination.—This clay is light yellow in color, has a fair degree of plasticity and burns to a fine brick red color. It slakes readily, breaking into very small particles. It required 25 per cent. of water to give to it its greatest plasticity. It may be subjected to high temperatures and dried rapidly without cracking and warping. It shrank 8.33 per cent. in drying, and when heated to the fusing point of cone .01 (1,130 deg. C.) it had shrunk 1.66 per cent. additional, making a total shrink-

age of 10 per cent., which is not excessive. At the fusing point of cone .01 (1,180 deg. C.) is was completely vitrified, had a dark red color, and a clear metallic ring. It had softened enough at this temperature so that it had commenced to change its shape a little. It was completely fused at cone 7 (1,270 deg. C.), and then had a dark red color with a very slight greenish tinge. A sample burned at the fusing point of cone .05 (1,050 deg. C.) had a good brick red color and was fairly hard, showing that this is about the temperature required for burning this clay.

It had a minimum tensile strength of 71 pounds to the square inch, a maximum of 92 pounds, while the ten briquettes tested showed an average of 81 pounds to the square inch. This is a very good tensile strength, and should insure a very small amount of breakage in the handling of the dried ware.

A study of this clay under the microscope shows that there are very few individual grains that are more than .05 mm. in diameter, while the larger part of the sample examined was composed of individuals that are about .025 mm. in diameter. There are also many grains that are much less even than this. The grains vary considerably in shape, some being rounded, while others are very irregular. There are quite a good many that are rectangular, and these are usually about twice as long as they are wide. The larger grains are mostly colored yellowish or brownish.

Quartz, feldspar, mica, and zircon were recognized.

The following chemical analysis shows the composition of this clay.

ANALYSIS OF CLAY FROM CHENEY, SPOKANE COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	64.98
Alumina (Al_2O_3)	15.57
Iron (Fe_2O_3)	5.34
Lime (CaO)	1.64
Magnesia (MgO)	0.94
Potash (K_2O)	1.40
Soda (Na_2O)	1.60
Titanium (TiO_2)	1.15
Moisture (H_2O)	2.75
Loss on ignition	4.33
Total	99.70
Total fluxes	12.27

The above chemical analysis shows this clay to be a little above the average, as regards the amount of silica, of clays used for the manufacture of common building brick. Clays are used, however, for this purpose which contain a very much higher percentage of siliça than this one does. The total amount of fluxing substances is about the average for clays used in the manufacture of common building brick.

This clay works smoothly and on the whole appears to be well suited for the manufacture of common building brick, repress and dry press brick, drain tile and material of this character.

DEER PARK.

Deer Park is a small town on the Spokane Falls and Northern Railway, in the extreme northwestern part of Spokane county and is twenty miles almost due north of the city of Spokane. It is in the same level basin-like area in which Clayton is situated, and the clay which is found around here is very similar to those found around that place. The clays around Deer Park are not being worked and have not been developed at any place.

Laboratory Examination.—One sample of this clay was examined in the laboratory with the following results:

The sample tested was white in color, had a good degree of plasticity, and a very smooth feel. It absorbs water and slakes rather slowly, breaking into very minute particles. It may be dried quickly without cracking or warping. It required 34 per cent. of water to temper it to its most plastic condition, shrank 6.66 per cent. in drying, and an additional 1.33 per cent. when heated to the fusing point of cone .01 (1,130 deg. C.). At this temperature, however, it had not completely vitrified, and was still soft. At the fusing point of cone 14 (1,410 deg. C.) it had completely vitrified and was steel hard, but showed no indication of fusing.

This clay showed a minimum tensile strength of 40 pounds to the square inch, a maximum of 88 pounds, while the average was 69 pounds to the square inch. Of the 12 briquettes tested, however, only two had a tensile strength of less than 60 pounds to the square inch.

The color of this clay after being heated to very high temperatures was but very little different from what it was before heating, being white with a very faint shade of yellow. The samples burned showed no signs whatever of cracking.

The following analysis shows the chemical composition of this clay:

ANALYSIS OF CLAY FROM DEER PARK, SPOKANE COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	51.22
Alumina (Al_2O_3)	33.52
Iron (Fe_2O_3)	1.72
Lime (CaO)	....
Magnesia (MgO)	trace
Alkalies (K_2O, Na_2O)	0.62
Moisture (H_2O)	1.38
Loss on ignition	11.16
Total	99.62
Total fluxes	2.34

The above analysis shows this clay to be low in silica, very low in total fluxes, with a high percentage of alumina.

The microscopic examination of it shows a few individual grains that are as much as .05 mm. in diameter, many that are about .02 mm. in diameter, while there are myriads of them that are .001 mm. and less in diameter. The larger grains are somewhat rounded while the smaller ones are more angular and irregular in shape. This clay is practically free from all gritty substances. On account of the smallness of the particles it was not possible to recognize the different minerals.

TRENT.

Trent is a station on the main line of the Northern Pacific Railway about eight miles east and two miles north of Spokane. A sample of clay was received from Mr. B. E. Smead of this place which looked promising and tests were made on it.

The sample was light, almost white in color, had good plasticity, and is fine grained. It required 28 per cent. of water to bring about its most plastic condition, had a shrinkage in drying of 6.66 per cent. and when burned at the fusing point of cone .05 (1,050 deg. C.) it showed no additional shrinkage. It had not vitrified, however, at this temperature and was not very hard. After burning it was of a light cream color. It had a

maximum tensile strength of 250 pounds to the square inch, a minimum of 200 pounds, with an average of 220 pounds to the square inch. The samples tested showed some checks after burning.

ANALYSIS OF CLAY FROM TRENT, SPOKANE COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	71.28
Alumina (Al_2O_3)	17.46
Iron (Fe_2O_3)	1.80
Lime (CaO)	0.40
Magnesia (MgO)	0.05
Potash (K_2O)	2.74
Soda (Na_2O)	0.28
Titanium (TiO_2)	0.70
Loss on ignition Moisture (H_2O)	5.30
Total	100.21
Total fluxes	5.97

The above analysis shows this clay to be high in silica, low in alumina and in the total amount of fluxing substances. The amount of iron is low and the burned ware should be light colored. Its composition is very similar to some of the stoneware clay found in the United States. (See page 28).

STEVENS COUNTY.

This county occupies the extreme northeastern corner of Washington, and is one of the large counties of the state. It is not, however, very thickly settled, and many of its industries are in their infancy. In a number of places in the county good clays are found, but only in a few of these are they being worked at the present time, as the local demand for building material manufactured from clay is small. At one place in the county, on account of the character of the clay, a large industry has been established, and the manufactured material is shipped to various places in the northwest, where it finds a ready market at good prices.

The clays of this county are of three different kinds so far as manner of formation is concerned. Along the streams, especially the larger ones such as the Columbia and the Pend d'Oreille, are large deposits of alluvial clays that are well suited for certain purposes. The most extensive and most important clay deposits in this county occur around Clayton. The deposits

are very extensive in this locality, covering a large area, and are of great thickness. They are largely of sedimentary origin, but some of them are probably residual.

CLAYTON.

Clayton is a small town situated on the Spokane Falls and Northern Railroad, and is in the south central part of Stevens county. It is about twenty-three miles north and six miles west of Spokane. The country around Clayton is practically level and has the appearance of a plain which extends in all directions for several miles. These clay deposits cover practically the whole of this plain, and are known to be, in places at least, many feet in thickness. They vary much in different places, in some being quite sandy, while in others they are very free from sand. They vary much also in color, in places being a light yellow, in others a dark yellow, while in still others they are a light gray, and in many places are almost pure white.

This area around Clayton is a basin, the drainage of which is to the south through Dragoon creek and its tributaries. Surrounding this basin on the north, east, and west are hills which rise from fifty to one hundred and fifty feet above it. These hills are composed of granite which is made up of quartz, feldspar, hornblende, and biotite. The feldspar forms a very large part of this rock. The granite is very coarse grained, the feldspar crystals in some cases being as much as two inches in length. It does not have a very large amount of quartz or biotite, the two most prominent minerals being the feldspar and the hornblende.

The granite decomposes quite readily, as is shown in places around the edge of the basin where large masses of it may be seen in the different stages of decomposition, from that where the very first stages occur, where the color has simply been changed but where the rock is still firm and solid, to that where the whole rock has been changed to a mass of sand and clay which is usually colored more or less by iron.

In some places in these clays there are considerable amounts of iron, which appears to have been deposited from solution, and in some cases it has cemented the clay together in nodules. In

other cases it occurs in layers in the clay extending continuously for some little distance, and has the appearance of an impure bog iron ore.

In places in this locality these clays have been prospected by borings to a depth of fifty feet and found to be practically the same for the entire distance.

They show very distinct stratification, indicating that they have been deposited in water. In places a few fossil leaves are found in these beds of clay.

The indications are that at one time this basin was filled with water and formed a lake. Into this lake from the north, east, and west sediments, formed from the decomposition of the granite, which composed the hills that formed the divides on these sides of the lake, were being washed. These sediments consisted of fine sands, clay, mica, and minerals of this character. The southern rim of this basin being the lowest is the one over which the water would flow first as it became filled with water and on this side then would be the outlet, or the stream flowing out of the lake. As time went on these sediments would keep filling the basin and the stream flowing out of it by deepening its channel, even though very slowly, would be tending to drain it and eventually the lake would be completely destroyed. Streams flowing out of lakes do very little work as a general thing in deepening their channels, on account of the fact that they have but little sediment when they issue from the lake, so that the filling up with sediments is more important in destroying lakes than the draining by streams, and in the case of this particular lake sedimentation was very important as is shown by the thickness of the clays.

Washington Brick, Lime and Manufacturing Company.— The main clay working plant operated by this company is located at Clayton. The company has opened these deposits in several places near its plant which is situated in the town of Clayton. The clays owned by this company are in Sec. 19, T. 29 N., R. 42 E. This company has a number of different grades of clay all of which, however, may be separated into about four different kinds, so far as color is concerned, as follows: A light

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yellow, a dark yellow, a light gray, and a white. The deposits are worked by an open cut or surface pit and practically the whole of the deposit, as deep as it is worked, is used. The main pit is about twenty yards from the mill. Above the clay is a thin layer of surface material which is of no value, and has to be removed. The face of the workings showed about six feet on the top, of a sandy light yellow clay, below which is three feet of a light gray somewhat sandy clay, and below this a layer six feet thick of white clay. The white clay continues six feet below the floor of the pit, and this part of this layer is said to be better than the best that is being used. The clay is worked with picks and shovels, loaded onto cars, and hauled to the mill by means of a horse, each grade of clay being kept separate.

Laboratory Examination.—The light yellow clay is quite uniform in color as it occurs in the bank. It absorbs water rapidly and slakes quickly. It is more or less sandy in its nature, and has only a medium amount of plasticity. It required 34 per cent. of water to temper it to its most plastic condition, had a shrinkage in drying of 5 per cent., and when heated to the fusing point of cone .01 (1,130 deg. C.) it had shrunk 6.66 per cent. additional. At this temperature it had vitrified but had not fused.

On heating at very low temperatures this clay becomes a very nice light brick red on account of the iron changing from a limonite to a hematite. When heated at a temperature of 1,050 deg. C. the color has changed again and is a light brown with a slight tinge of red and when heated still higher to to the fusing point of cone 14 (1,410 deg. C.) it has changed to a gray which is probably due to the fact that the iron has changed from an oxide to a silicate. After having been heated to this temperature the clay was hard.

This clay has a minimum tensile strength of 38 pounds to the square inch, a maximum of 53 pounds, while the ten briquettes tested showed an average of 44 pounds to the square inch. While this is not a high tensile strength, still there should not be a large amount of loss in the handling of the dry ware. It allows of rapid drying without warping and cracking and the

samples tested showed practically no signs of cracking in burning.

When studied with the microscope, this clay is seen to be made up of grains a few of which are as much as 1.5 mm. in diameter. The larger part of it, however, is a mass of grains of about .01 of a mm. and less in diameter. The larger grains are stained with iron while the smaller ones are clear and appear to be practically free from it. The individual grains as a general thing are rounded or sub-angular.

This clay does not feel very rough, but when taken between the teeth it shows a considerable amount of grit. The main minerals recognized were white mica, quartz, and feldspar.

The dark yellow clay used by the Washington Brick, Lime and Manufacturing Company at Clayton is obtained a short distance southwest of the openings from which the other clays are obtained. This, like the other clay deposits, is worked by means of an open cut, the clay being loaded into wagons and then hauled to the plant.

This clay is a darker yellow than the one described above, is finer grained, and had only a medium degree of plasticity. It dried rapidly without cracking or warping. It required 23 per cent. of water to bring it to its most plastic condition, had an air shrinkage of 4.60 per cent., and when heated to the fusing point of cone .010 (950 deg. C.) it had no additional shrinkage, was light red in color and was not very hard. When burned at the fusing point of cone .05 (1,050 deg. C.) it had a nice brick red color, was hard and had a clear metallic ring. At the fusing point of cone .01 (1,130 deg. C.) it had a fire shrinkage of 2.5 per cent. At this temperature it was vitrified, had a very dark brown color, and a smooth glossy surface. When heated to this temperature it softened enough so that it began to lose its form. Complete fusion took place at cone 6 (1,250 deg. C.). On account of the considerable amount of iron which this clay contains it was necessary in testing the fusibility to heat it very gradually or else it would swell and the cones would lose their shape and poor results would be obtained.

This clay showed a minimum tensile strength of 75 pounds to

the square inch, a maximum of 100 pounds, while the average shown by the nine briquettes tested was 88 pounds to the square inch, which is a very good average. It absorbs water rapidly and slakes quickly breaking into very small particles.

When viewed under the microscope it is seen to be made up of grains which vary considerably in size. The largest grains are as much as 1 mm. in diameter, but these form but a very small part of the sample. These larger grains are sub-angular to angular and most of them are colored brownish or yellowish. There are many grains that are about .15 of a mm. in diameter, but the larger part of this clay is made up of individuals that are about .05 of a mm. in diameter. Scattered among these, however, are many that are .01 of a mm. in diameter and less.

These medium sized and small grains are practically all of them very irregular in outline and sharp cornered. Many of them are clear and transparent while others are brownish and yellowish.

Feldspar, quartz, muscovite, biotite, chlorite, and zircon were recognized in this sample. There is a considerable amount of gritty material in this clay.

The light gray colored clay is obtained from an opening only a few rods from the plant. This clay is very plastic, has an air shrinkage in drying of 9.16 per cent., and a fire shrinkage when burned at the fusing point of cone .01 (1,130 deg. C.) of 5.84 per cent. Thus in drying and burning it would have a total shrinkage of 15 per cent. which is a large amount of shrinkage. It may be dried rapidly however, without cracking or warping and the samples tested burned without any cracking, whatever.

This clay has a slick greasy feel, it absorbs water quite readily and separates along the planes of lamination into thin layers, but does not slake completely. The minimum tensile strength shown by the samples tested was 70 pounds to the square inch. Only three, however, of the ten briquettes tested showed a tensile strength of less than 109 pounds to the square inch. The maximum was 158 pounds and the average was 114 pounds to the square inch. When burned at the fusing point of cone .01 (1,130 deg. C.) it was vitrified, had a clear metallic ring, and

had changed to a very light cream color. At this temperature it retained its form perfectly and was not fused at the melting point of cone 14 (1,140 deg. C.)

When examined under the microscope this clay is found to be made up of grains which vary considerably in size, but all of them are small. The largest grains observed were .05 of a mm. in diameter. Grains having a diameter of about .012 of a mm. are scattered promiscuously among the multitudes of small individuals which are .002 of a mm. and less in diameter. The large grains are slightly colored and somewhat rounded while the smaller ones are irregular in outline.

Individuals of quartz, feldspar, and white mica were observed in the sample that was examined. This clay has no taste or odor and when tested between the teeth it gives no evidence of having any grit.

The white clay used by the Washington Brick, Lime and Manufacturing Company has a smooth, greasy feel and a good degree of plasticity. It works very smoothly and may be dried rapidly without cracking or warping. It required 34 per cent. of water to temper it to its most plastic condition and in drying had a shrinkage of 10 per cent. and when heated to the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 4.5 per cent. At this temperature it had completely vitrified, was steel hard, and had a clear metallic ring. It had not fused, however, and retained its form perfectly. After being heated to this temperature it was almost pure white in color, having changed practically none.

The tests showed it to have a minimum tensile strength of 84 pounds to the square inch, a maximum of 121 pounds, while the twelve briquettes tested gave an average of 100 pounds to the square inch. This is a good high tensile strength and would insure a very small amount of loss from breakage in the handling of the dried ware before it is burned.

The samples tested showed no signs whatever of warping or cracking in drying or burning. When heated to the fusing point of cone 14 (1,410 deg. C.) it showed no signs of fusing and had changed practically none in appearance from what it

was after being heated to the fusing point of cone .01 (1,180 deg. C.) except that it was a little harder. This clay absorbs water and slakes quickly, breaking down into very small particles.

A microscopic examination of this clay shows that it is made up of grains which vary considerably in size, the largest being about .05 of a mm. in diameter. Many of the individual grains are not more than .005 of a mm. in diameter while some are even less than this. The larger grains are rounded or subangular, but the smaller ones are in the main very irregular in outline. This is a fine grained clay, but when tested between the teeth shows an occasional very fine grain of gritty substance. The amount is so small, however, and the grains so minute that it is hardly noticeable.

The following chemical analyses show the composition of these different clays:

ANALYSES OF CLAYS FROM CLAYTON, STEVENS COUNTY.

W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.	III.	IV.	V.
Silica (SiO_2)	62.56	65.80	49.67	53.64	51.36
Alumina (Al_2O_3)	23.96	18.78	32.38	31.96	33.09
Iron (Fe_2O_3)	4.70	5.42	1.50	1.82	2.39
Lime (CaO)			0.25		
Magnesia (MgO)	trace	2.46	0.58	trace	0.78
Alkalies (K_2O, Na_2O)	1.12	3.39	1.35	1.17	0.08
Titanium (TiO_2)			0.51		
Moisture (H_2O)	.92	1.38	2.30	1.66	2.12
Loss on ignition	6.84	3.14	10.92	10.06	10.54
Total	100.10	100.37	99.46	100.31	100.36
Total fluxes	5.82	11.27	4.19	2.99	4.25

I. Light yellow clay.
II. Dark yellow clay.
III. Light gray clay.
IV. White clay with some sand.
V. Best white clay.

From the above analyses it is seen that there is no very great difference in the composition of the two samples of the yellow clay from this locality. Both of them are about an average, as regards the amount of silica they contain, of the clays used for the manufacture of common building brick. Number I. contains 5 per cent. more alumina than the other and is high in this element. The total fluxes are low in No. I., the alkalies

being especially low, while in the other the iron, alkalies, and magnesia are all of them fairly high and this accounts for this clay fusing at lower temperatures than No. I.

Numbers III., IV. and V. are all low in silica and high in alumina. They are also all of them extremely low in total fluxes, the amount in the best white clay being only 4.25 per cent. and in the others it is even less than this. One of the striking things about all of these samples is the very small amount of alkalies.

The composition of these clays along with the physical properties which they have make them very valuable for various purposes.

The Washington Brick, Lime and Manufacturing Company uses these different clays either alone or in various combinations in the manufacture of dry press or repress facing brick, sidewalk brick, and terra cotta. They make many different shades and colors both of brick and terra cotta, by using these different clays mixed in various proportions, from white to red with many shades between.

Description of the Plant.—The plant of the Washington Brick, Lime and Manufacturing Company, located at Clayton, is the largest clay working plant in eastern Washington.

The clay on being brought from the bank is dumped in piles in the mill, the different kinds or grades being put in separate piles. When a certain kind of ware is to be made clay is taken from the different piles in given amounts and supplied to the crushers where it is ground and mixed. The grinding is done on two large dry pans, and after it is ground and mixed it is carried by means of conveyors to the top of the mill where it is screened, the clay that goes through the screens going into bins while the clay that passes over the screens goes back to the dry pans. From the bins the clay is conveyed by troughs or spouts directly to the different brick machines.

The company has two dry press machines with a capacity of about 5,000 to 6,000 brick each per day. These are used, however, only in the manufacture of the best grades of facing brick. There is a long horizontal pug mill for tempering the clay to

be used for stiff mud brick and the clay, after being thoroughly tempered, is fed into the brick machine which is an auger stiff mud machine with a capacity of about 25,000 brick a day. There is one hand power wire cutting table and one repress machine having a capacity of 30,000 repressed brick a day. There is also one chaser mill to temper the clay used in the manufacture of terra cotta. The brick are taken from the repress machine, placed on small cars and run into the dry kiln, the kiln being steam heated.

The brick are all burned in circular down draft kilns, there being seven of these, each having a capacity of from 36,000 to 80,000 brick. There are also three muffle kilns in which the terra cotta is burned. The brick machinery and the terra cotta works have all been in one large building up to the present time (January 1907), the molding room, the drafting room, and the drying room for the terra cotta all being on the second floor in one end of the building. A large new building has just been completed, however, for the terra cotta works.

The two boilers, one an 80 and the other a 40 horse power, furnish steam for an 80 horse power engine, which drives the machinery, and also for heating the drying rooms. There are also the necessary warehouses and sheds in which to store the burned ware.*

Spokane Pottery Company.—The plant of this company is located at Clayton, but the clay bank is about six miles north of the town, and is in Sec. 32, T. 30 N., R. 42 E. These deposits, at the place where they have been uncovered and worked, are distinctly stratified and lie in practically a horizontal position. They have been opened up at two or three places and a small amount of prospecting done. They are worked by means of an open cut or surface pit and the clay loaded onto wagons and hauled by means of teams to the plant at Clayton.

The face of the pit showed an exposure of about twenty feet of clay, only about eight feet at the bottom, however, being suitable for pottery, and in order to get this the upper ten or

*NOTE.—Since the above was written the plant of the Washington Brick, Lime and Manufacturing Company has been very much enlarged and improved.

twelve feet must be removed, and as it is not used for anything, it adds that much to the cost of the pottery clay. The clay at this place appears to vary considerably in character. In places it becomes sandy and has but little plasticity.

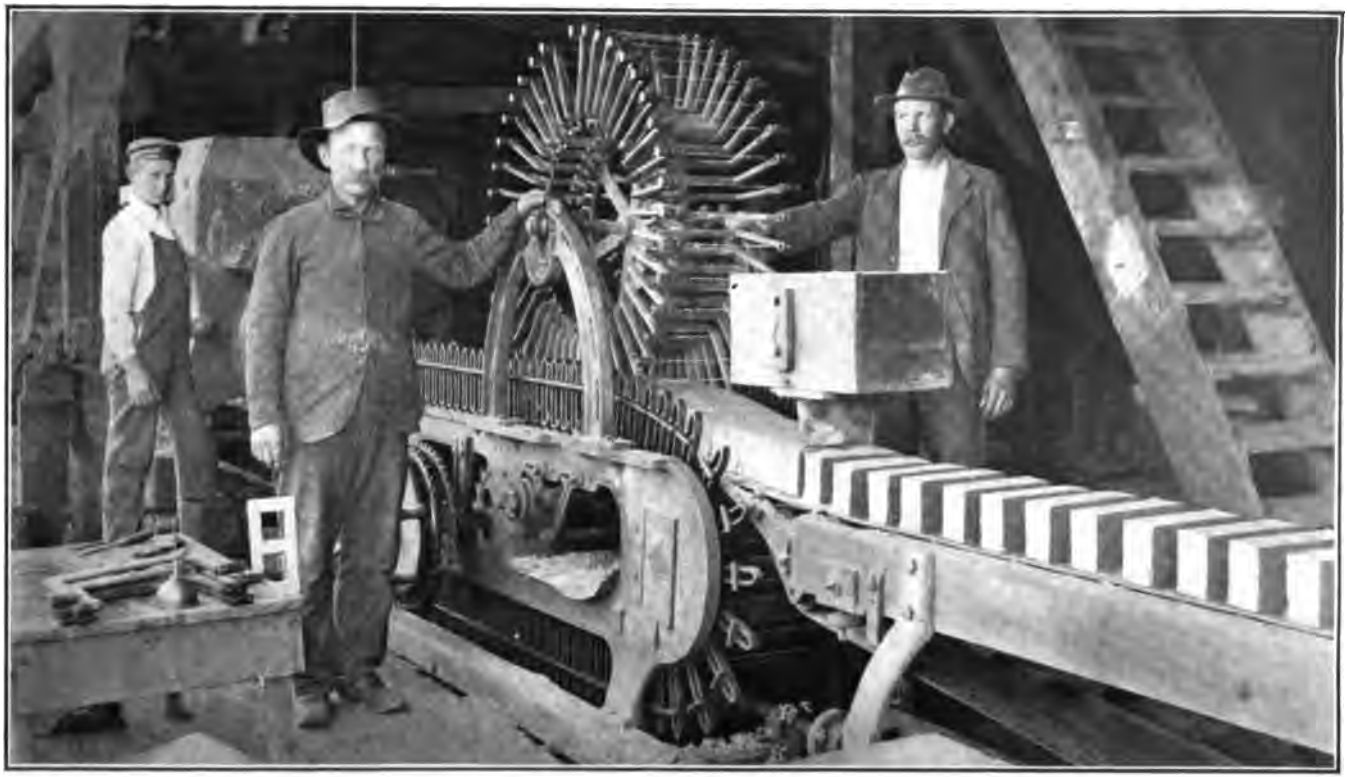
The extent of these deposits is not very well known as they have been but little developed or prospected. The light yellow clays which are so common around Clayton, as the surface clay, are found practically all the way from Clayton to the place where these clays occur, and in all probability careful and systematic prospecting by boring would show the presence of good pottery clay beneath this yellow clay in many places.

Laboratory Examination.—This clay is almost white in color, has a slick, greasy feel, and absorbs water and slakes quickly, breaking into small particles. The samples tested showed a minimum tensile strength of 91 pounds to the square inch, a maximum of 127 pounds, while the ten briquettes tested showed an average of 112 pounds to the square inch. This is a good tensile strength and is about the average of some of the best clays that are being used in the manufacture of stoneware.

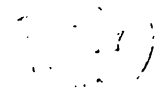
It required 30 per cent. of water to temper it to its most plastic condition. It had an air shrinkage in drying of 6.66 per cent. and when burned to the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 1.66 per cent. After heating to this temperature it was almost pure white, was about six in hardness or a little less than good steel, and had a fairly clear metallic ring. It was not entirely vitrified at this temperature and would probably shrink a little more on being heated to a higher temperature.

When thoroughly tempered it was very plastic, worked smoothly, could be formed into almost any shape desired, and also retained it extremely well.

At the melting point of cone 14, (1,410 deg. C.) it showed no signs of melting, the sharp point of the cone remaining perfectly straight. A sample of this clay was tested by Prof. Edward Orton, Jr., Columbus, Ohio, and found to fuse at cone 29 or about 1,710 deg. C. It is considered by him as No. 2 refractory grade, and would be able to withstand the temperatures



INTERIOR VIEW, SHOWING BRICK MACHINE USED AT ABRAHAMSON YARD, SEATTLE



of all ordinary uses, such as pottery kilns, boiler settings, and things of this kind. This clay is free from gritty material and the individual grains are so small that it was not possible to recognize them even under the microscope. Analyses of this clay showed the following results:

ANALYSES OF CLAY FROM SIX MILES NORTH OF CLAYTON, STEVENS COUNTY.
W. R. BLOOR, Analyst.

Silica (SiO_2)	65.66	58.06	61.64
Alumina (Al_2O_3)	21.96	29.04	24.20
Iron (Fe_2O_3)	1.92	1.82	2.10
Lime (CaO)			0.30
Magnesia (MgO)	0.90	1.02	0.78
Potash (K_2O)	0.80	1.75	2.38
Soda (Na_2O)			0.16
Titanium (TiO_2)			0.50
Moisture (H_2O)	1.68	1.18	0.52
Loss on ignition	6.66	7.56	7.56
Total	99.60	100.43	100.14
Total fluxes	3.62	3.59	6.12

The above analyses show this clay to have about the same composition as that of some of the best stoneware clays of the United States. The percentage of silica is a little below the average of some of the best of this class of clays. The average amount of silica in the Ohio clays used in the manufacture of stoneware is given by Orton* as 65.09 per cent., while the average amount of fluxing matter is 4.44 per cent.

It was formerly thought that a clay, to be suitable for the manufacture of stoneware should have a high silica content in order that it might be successfully salt glazed. This feature, however, is of little importance now as other kinds of glazes have almost completely taken the place of the salt glaze.

While the percentage of silica as shown by the analyses of this clay is below the average, it is only a little below, and good stoneware clays occur in which it is much lower than this. The amount of fluxing matter is below the average of most clays used for the manufacture of stoneware, while the amount of alumina is high.

The physical properties of this clay are such as to make it well

*Ohio Geol. Survey, Vol. VII, p. 95, 1893.

suited for the manufacture of stoneware. It has a good degree of plasticity and works easily and smoothly. It has a tensile strength above the average of the clays used for this kind of ware. The amount of shrinkage in drying and burning is not excessive and it burns to a dense, hard body. This clay has the properties of a good stoneware clay.

Description of the Plant.—This company has the largest and most complete equipment of any stoneware plant in Washington. For making stoneware by what is known as the jollying or jiggering process, there is one pan and cover wheel, one jug wheel, one jumbo wheel, and one flower pot wheel. There is also one flower pot press for making flower pots from two to six inches in diameter.

The plant is also supplied with four turning wheels on which the various kinds of turned ware are made.

The clay is all prepared for use by being thoroughly mixed and tempered in a chaser mill. The machinery is all operated by steam power, which is furnished by a thirty horse-power engine and a seventy horse-power boiler. This boiler also furnishes steam for heating the drying rooms.

The building is 80 by 100 feet and in this are two large dry rooms each 20 by 40 feet and one large slip room where the slips are applied to the ware. The ware is all burned in circular down draft kilns. There are three of these each having a capacity of 8,000 gallons.

The capacity of the plant is about 1,000,000 gallons a year.

The ware is all shipped to various points in the northwest and finds a ready market at good prices.

Colville Valley.

The Colville valley is a long, narrow valley along the Colville river. On the east and west sides of the valley and parallel with it are low mountain ridges. The Colville river is a very slow flowing sluggish stream along which is considerable marshy, swampy land. Clays are found in many places throughout the valley, but on account of the local demand being small and the fact that, in most places at least, these clays are suited only

to the manufacture of the very commonest grades of clay ware, they are being used in but a few places.

COLVILLE.

The principal town in the Colville valley and the county seat of Stevens county is situated in the northern part of the valley on the Spokane Falls and Northern Railway. The clay which occurs around the town, as a general thing, contains considerable sand and hence does not have very good plasticity. Some very good building brick, however, have been made here. Two small yards are being operated, one a short distance east and the other a little north of town. In each case the brick are dried in the open air and burned in temporary rectangular kilns.

CHEWELAH.

Clays are found around Chewelah and one small yard is in operation. The brick are made by the stiff mud process, dried in the open air, and burned in temporary rectangular kilns.

VALLEY.

About two miles east of Valley a bed of almost pure white clay occurs. No work to speak of has been done to open up this clay, and it is not possible to say definitely just how large a body there is of it. The indications are, however, that the deposit is a large one. Only a few preliminary tests have been made so far, but these indicate that this is a good clay. It has good plasticity, is very fine grained, and judging from appearances and chemical analysis, should require a high temperature to fuse it.

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM VALLEY, STEVENS COUNTY.
A. A. HAMMER, Analyst.

Silica (SiO_2)	69.12
Alumina (Al_2O_3)	23.40
Iron (Fe_2O_3)	0.96
Lime (CaO)	trace
Magnesia (MgO)	0.92
Potash (K_2O)	0.17
Soda (Na_2O)	0.15
Loss on ignition	4.92
Total	99.64
Total fluxes	2.20

The analysis shows this clay to have a very small amount of each of the fluxing substances. The amount of iron is especially low and this clay when burned should be very light in color.

NEWPORT.

Newport is a town in the extreme southeastern part of Stevens county. It is on the bank of the Pend d'Oreille river where it enters Washington. The main line of the Great Northern Railway passes through the town.

The clay deposits which occur here are found in a low knoll a little to the south and east of the town. No development has been done on these deposits up to the present time. Small openings have been made in a number of places, however, to determine something in regard to the extent of the deposits and to procure samples of the clay for testing. So far as could be told the clays seem to have a considerable extent. They outcrop along the side of this knoll in various places.

There are two grades of clay found here, one being white in color while the other is yellow. Both appear to be stratified, the beds occupying practically a horizontal position. Samples of both of these clays were obtained and analyzed and tested in the laboratory.

Laboratory Examination.—The white clay is quite sandy, has very little plasticity, and on account of this no physical tests were made of it.

The yellow clay from here has a good degree of plasticity. It has a slick, slightly greasy feel, absorbs water and slakes quickly, separating into very thin, small flakes. It required 30 per cent. of water to temper it to its most plastic condition, it shrank 8.33 per cent. in drying, and when burned at the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of 1.65 per cent. At this temperature, however, it had not vitrified, was light red in color, and was not very hard. When heated to the fusing point of cone .05 (1,050 deg. C.) it was dark red in color, almost steel hard, and had a fairly good me-

tallic ring. This clay fused at the melting point of cone 6 (1,250 deg. C.).

It showed a minimum tensile strength of 91 pounds to the square inch, a maximum of 150 pounds, while the average of the ten briquettes tested was 109 pounds to the square inch, which is a very good tensile strength.

The following chemical analyses show the composition of these clays:

ANALYSES OF CLAYS FROM NEWPORT, STEVENS COUNTY.

W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.
Silica (SiO_2)	74.23	59.22
Alumina (Al_2O_3)	19.08	20.04
Iron (Fe_2O_3)	1.07	5.76
Lime (CaO)	trace	1.54
Magnesia (MgO)	0.54	2.33
Alkalies (K_2O, Na_2O)	0.47	5.05
Titanium (TiO_2)	.....	0.06
Moisture (H_2O)	0.20	1.64
Loss on ignition	4.52	3.76
Total	100.06	99.50
Total fluxes	2.08	14.74

I. White clay.
II. Yellow clay.

The analyses show the white clay to be high in silica but very low in the total fluxing substances, while the yellow clay is lower in silica but is high in iron and alkalies, with some lime and magnesia, so that the total fluxing substances are quite high.

The largest grains observed by the aid of the microscope in the white clay have a diameter of about .1 of a mm. while there are many that have diameters of about .06 of a mm. The larger part of the samples was made up of grains about .003 of a mm. and less in diameter. The larger grains are fairly well rounded and some of them are slightly stained yellowish and brownish. Many of the smaller grains are quite angular in outline. This clay has a rough feel and contains a considerable amount of sandy, gritty material.

Pend D'Oreille River.

At a number of places along the Pend d'Oreille river between Newport and Box Canyon are large deposits of alluvial clays. What is usually known as the "Blue Slide" is a large body of this clay which has a bluish color especially when wet. This clay has not been used for any purpose, so far, on account of the fact that it is not easily accessible and is so situated that the manufactured material would have to be shipped long distances to market.

A little above the upper end of Box Canyon are quite extensive clay deposits. At this point a small town has been established and considerable work done with a view to the manufacture of Portland cement, the intention being to use these clays to mix with the limestone which occurs at this place.

Only one sample of the clays which occur along the Pend d'Oreille river was tested and analyzed, and this was from Portland, a little town where the cement plant was to have been established.

This clay is distinctly stratified and when dry is hard, almost like shale. It is gray in color, absorbs water slowly, but does not slake. It has a fair degree of plasticity, a minimum tensile strength of 204 pounds to the square inch, a maximum of 227 pounds, while the eight briquettes tested showed an average of 243 pounds to the square inch. This is a very high tensile strength for clay.

It required 22.5 per cent. of water to bring it into its most plastic condition. It shrank 5.83 per cent. in drying, and 4.16 per cent. additional when heated to the fusing point of cone .01 (1,130 deg. C.). After having been heated to this temperature it was dark red in color, had a hardness about equal to that of steel, and a clear metallic ring. This clay began to fuse at the melting point of cone 6 (1,250 deg. C.) and was completely fused at the melting point of cone 8 (1,290 deg. C.). It showed a tendency to crack in drying when subjected to high temperatures and dried quickly.

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM PORTLAND, STEVENS COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	61.58
Alumina (Al_2O_3)	20.29
Iron (Fe_2O_3)	5.95
Lime (CaO)	1.34
Magnesia (MgO)	2.30
Alkalies (K_2O, Na_2O)	2.01
Moisture (H_2O)	1.94
Loss on ignition	4.14
Total	99.55

The above analysis shows nothing out of the ordinary as regards this clay. The amount of silica and alumina is about the average for common brick clays. The total amount of fluxing material in it is not excessive and the amount of the alkalies is small.

The following partial analysis of this same clay is from Prof. Henry Landes' report of the cement resources of Washington, published in Bulletin 285 U. S. Geological Survey, Washington, D. C., p. 382:

ANALYSIS OF CLAY FROM PORTLAND, STEVENS COUNTY.

Silica	64.10
Aluminum and iron oxides	22.30
Calcium carbonate	1.60
Magnesium carbonate	trace

This shows a little higher per cent. of silica and a smaller amount of iron and aluminum than the other analysis.

The microscope shows this clay to consist of a mass of grains, most of which are very sharp cornered and irregular in outline. A few of these grains are as much as .1 of a mm. in diameter, a considerable number of them are .05 of a mm. in diameter, but by far the larger part are .005 of a mm. and less in diameter. The larger grains are colored brownish and greenish, while the smaller ones are colorless and clear. Individuals of quartz, feldspar, mica, calcite, and zircon were observed in the sample examined.

This clay has a rough feel and contains a considerable amount of gritty material.

Columbia River.

In a number of places along the Columbia river in Stevens county, and where it forms the boundary between Stevens and Ferry counties, large deposits of alluvial clay are found. In only a few places, however, so far as the writer knows, have these clays been utilized at all and at these places only to a very small extent.

NORTHPORT.

Clay is found in places around Northport and at different times a few brick have been made from it. About two miles above the town, on the Columbia river, large deposits of clay occur. This clay varies much in composition, some of the layers being very sandy, while others are quite free from sand and very plastic. To the south and east of town a short distance is some very good appearing plastic clay, which at one time was used in the manufacture of common building brick.

The following analyses show the composition of these clays:

Analyses of Clays from Northport, Stevens County.

A. A. Hammer, Analyst.

Silica (SiO_2)	56.72	59.76
Alumina (Al_2O_3)	15.69	17.39
Iron (Fe_2O_3)	9.34	5.71
Lime (CaO)	4.43	2.94
Magnesia (MgO)	3.13	4.11
Potash (K_2O)	1.19	1.51
Soda (Na_2O)	1.09	1.51
Loss on ignition	6.64	6.86
Total	98.23	99.99
Total fluxes	19.18	16.06

The most striking thing shown by the above analyses is the high percentage of fluxing substances which these clays contain. These clays would probably make building brick of fair quality, but would not be of much value for other kinds of clay products.

BOSSBURG.

This is a small town situated on the Columbia river in the northern part of Stevens county. The Spokane Falls and Northern Railroad, which is a branch of the Great Northern

S. Shedd, Photo. PLANT OF THE PONTIAC BRICK COMPANY, SEATTLE

Railway, also passes through the town. Near this place along the river is a large deposit of clay which when wet is very dark with somewhat of a bluish color and when dry is a light gray. This deposit has been worked a little at different times, some of the clay having been shipped to Clayton and used by the pottery people there for glazing their stoneware.

Laboratory Examination.—This clay is very plastic and easily worked. It absorbs water and slakes very quickly, separating into a mass of thin flat scales which finally break down into very small grains.

It required 34.5 per cent. of water to temper and make it most plastic, shrank 6.68 per cent. in drying and when heated to the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of 1.33 per cent. At this temperature, however, it had not completely vitrified and had not become very hard. After having been heated to this temperature it was light red in color. When heated to the fusing point of cone .05 (1,050 deg. C.) it had vitrified, was steel hard, had a dark red color, and a clear metallic ring. On account of the large amount of iron it contains it was necessary to heat it very slowly to prevent swelling and changing of shape before the fusing point was reached. It was completely fused at the fusing point of cone 1 (1,150 deg. C.). After fusing it had a smooth surface and a dark brown color.

The sample tested showed a minimum tensile strength of 88 pounds to the square incha, a maximum of 142 pounds, while the eight briquettes tested showed an average of 118 pounds to the square inch. Although a very fat plastic clay, it appears to be of such a nature that it may be dried quite rapidly without danger of cracking and warping. The samples used in burning were small, but they showed no signs whatever of cracking. This clay is perfectly free from gritty material and the individual particles are so extremely small that even under the microscope it was not possible to recognize the different minerals.

Two samples of this clay were analyzed, one having been ob-

tained direct from the deposit, while the other was obtained from the Spokane Pottery Company at Clayton:

ANALYSES OF CLAY FROM BOSSBURG, STEVENS COUNTY.
W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.
Silica (SiO_2)	52.94	51.12
Alumina (Al_2O_3)	22.12	21.26
Iron (Fe_2O_3)	6.72	9.12
Lime (CaO)	2.99	3.48
Magnesia (MgO)	3.91	4.26
Alkalies (K_2O, Na_2O)	4.62	3.29
Moisture (H_2O)	1.56	1.34
Titanium (TiO_2)	0.06	.....
Loss on ignition	4.98	5.70
Total	99.90	99.57
Total fluxes	18.10	20.15

I. From Pottery Company at Clayton.

II. From deposit near Bossburg.

The above analyses show this clay to be low in silica and to have perhaps a little above the average amount of alumina. The most striking thing about it, however, is the large amount of iron and the very large amount of the total fluxing substances that it contains. The effect of this is shown in the low temperature, cone 1 (1,150 deg. C.), at which it fuses.

On account of fusing at a low temperature to a smooth, glossy surface and rich brown color it appears to be well suited as a natural glaze for stoneware. It is suited also for the manufacture of brick and drain tile, but for such wares better results would be obtained if it could be mixed with sand or a sandy clay, as in this way the shrinkage would be less and the danger from warping and cracking in drying and burning would not be so great.

KETTLE FALLS.

Large clay deposits are found at Kettle Falls, especially along the Columbia river. The clay here is grayish in color and much of it has good plasticity. The deposits are well stratified and the different layers appear very uniform in composition. One small yard is operated here and a fair grade of common building brick is being produced.

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM KETTLE FALLS, STEVENS COUNTY.
A. A. HAMMER, Analyst.

Silica (SiO_2)	56.98
Alumina (Al_2O_3)	17.74
Iron (Fe_2O_3)	7.22
Lime (CaO)	5.25
Magnesia (MgO)	4.06
Potash (K_2O)	1.81
Soda (Na_2O)	0.86
Loss on ignition	6.07
Total	99.81
Total fluxes	18.72

The amount of iron, lime, and magnesia is large, the percentage of each being high, and would cause this clay to fuse at a low temperature.

LINCOLN COUNTY.

Lincoln county is situated entirely within the Columbia plain area, the rocks throughout the county are basalt, and on account of this a person would hardly expect to find anything in the nature of clay in this locality except that which has been formed by the decomposition of the basalt. The clays are mostly residual and are widely distributed in the county. They vary much, especially as regards physical properties, but in places are well suited for use in the manufacture of building brick, drain tile and things of this character.

MONDOVI.

Only one sample of clay from Lincoln county was tested in the laboratory, and this was from Mondovi, a station on the Washington Central Railway in the northeastern part of the county. There is a large body of clay at this point and it is also well situated as regards transportation of the manufactured ware as it occurs along by the sidetrack at this place.

Laboratory Examination.—This clay is light brown in color, has a fairly smooth feel, and very little gritty material in it. It absorbs water rapidly and slakes quickly, breaking up into very small particles. The sample tested showed a minimum

tensile strength of 60 pounds to the square inch, a maximum of 86 pounds, and an average of 70 pounds to the square inch.

It required 24.5 per cent. of water to temper it to its most plastic condition and had an air shrinkage in drying of 10 per cent. When heated to the fusing point of cone .010 (950 deg. C.) it showed no fire shrinkage, was a brick red in color, and fairly hard. When heated to the fusing point of cone .01 (1,130 deg. C.) it was very dark red in color, had completely vitrified, and had the hardness of steel. After being heated to this temperature it showed a fire shrinkage of 3.33 per cent. and had a good metallic ring.

It completely fused at cone 6 (1,250 deg. C.) and was slightly greenish in color.

The following analysis shows the chemical composition of this clay:

ANALYSIS OF CLAY FROM MONDOVI, LINCOLN COUNTY.
W. R. BLOOR, Analyst.

Silica (SiO_2)	60.52
Alumina (Al_2O_3)	19.37
Iron (Fe_2O_3)	5.95
Lime (CaO)	1.94
Magnesia (MgO)	1.65
Alkalies (K_2O, Na_2O)	1.99
Moisture (H_2O)	4.02
Loss on ignition	4.74
Total	100.18
Total fluxes	11.53

The above analysis shows nothing very striking as regards this clay. It has about an average amount of silica and alumina for clay used in the manufacture of ordinary building brick. The total amount of fluxing substances, however, is somewhat below the average for clays of this class.

Its physical properties are such that if used alone it would require very careful handling to prevent a considerable amount of loss. It is very fat and plastic and has a tendency to warp and crack in drying, especially if dried rapidly. It is apt to crack more or less also in burning.

The tendency to crack while drying might be overcome by drying slowly, but this adds expense. If sand or sandy clay could be had in this locality it could be mixed with the clay and

the trouble from this cause obviated. While it is true the tensile strength is not overly high, still some non-plastic material might be mixed with it without hurting this property seriously.

Whitman County.

Whitman county is situated on the extreme eastern border of the state and is the next county south of Spokane county. The country rock throughout the county is mainly basalt, but there are a few places within the county where granite and quartzites are known to occur. These, however, are found exposed on the surface in only a few places and are of very limited extent.

To the east of Whitman county only a short distance, in Idaho, granitic mountains rise above the basaltic plateau and the rocks are practically all granites or gneisses or rocks of this general character.

This county is drained mainly by the Palouse river and its tributaries, the source of which is in these granitic mountains to the east of it. By the decomposition of these granites clays have been formed and these, by gravity and surface wash, have finally found their way into the Palouse river and have been transported for longer or shorter distances by it and then deposited.

The principal clays found throughout Whitman county are residual deposits that have been formed from the decomposition of basalt. Clays of this character are widely distributed and very abundant. These are suited for the manufacture only of the common grades of clay products, such as building brick, tile, flower pots, and wares of this general character. Only in a few places in the county are these clays being worked and these are around some of the larger towns simply to supply the local demand.

In some places these clays are well suited for the manufacture of ordinary building brick, repress facing brick, and drain tile. In many places they are so fat that they have to be handled very carefully in drying and burning to prevent warping and cracking. Where sand may be had to mix with this clay this

tendency may be overcome. They have a rather large amount of shrinkage and this would also be decreased if sand were mixed with them. In some places this clay also contains more or less soluble salts which are often brought to the surface of the bricks by the water taking them into solution and depositing them on the walls of the buildings, in which these bricks have been used, when it evaporates. This might be overcome by the addition of some substance that, during the burning, would change these soluble salts to insoluble salts, or by adding some substance that would change them to a very soluble form so that they may be very readily washed from the walls. The substance commonly added is barium, either as a chloride or as a carbonate, and when the clay is burned this may form either an insoluble or a very readily soluble salt, depending upon what the soluble salt is in the clay.

PALOUSE.

Large deposits of this alluvial clay are found along the Palouse river and especially near the town of Palouse and to the east of it. The clay occurs in distinct layers and is therefore of undoubted sedimentary origin. It is white in color and closely resembles kaolin and has certainly been formed from a rock containing a large amount of feldspar. The principal place where this clay is being utilized is about one half mile from the Palouse river, near the town of Palouse.

Palouse Pottery Manufacturing Company.—The clay working plant of this company is located in the town of Palouse which is on the branch line of the Northern Pacific Railway that extends from Spokane, Washington, to Lewiston, Idaho. The clay being used by this company is obtained from near Potlatch, Idaho, which is about twelve miles east of Palouse.

The clay bed, at the place where this company is working it, has a thickness of about fifteen feet and is overlaid by from eight to ten feet of soil. The deposit varies much, in places being quite sandy, while in others it contains considerable iron and has a yellowish color. Much of the deposit, however, is practically free from both of these and of good quality. The deposit is worked by means of a shaft and drifts, and the clay

is loaded into wagons and hauled by teams to Potlatch where it is loaded onto cars and shipped to the plant at Palouse. The deposit at this place is a large one, covering a considerable area.

Laboratory Examination.—Two samples of this clay were obtained for testing, one appearing to be a little more sandy than the other. Chemical analyses were made of both of these but for the physical tests the two samples were thoroughly mixed and a sample taken from the mixture.

This clay is white in color, has a very smooth, greasy feel, is plastic and easily worked into any form desired, and also retains this form well. It may be subjected to high temperatures and dried rapidly without warping and cracking. There is also very little tendency to crack in burning.

It has a good tensile strength; the minimum of the samples tested was 64 pounds to the square inch, the maximum 118 pounds, and the average shown by the ten briquettes tested was 88 pounds to the square inch. It required 34 per cent. of water to temper it to its most plastic condition, had a shrinkage in drying of 8.33 per cent., and heated to the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 5.66 per cent. After being burned at this temperature it was completely vitrified, had a clear metallic ring and was a very light cream in color. At still higher temperatures the color remained practically the same.

It absorbs water and slakes readily, breaking into very small particles.

The following analyses show the chemical composition of two samples of this clay:

ANALYSES OF CLAY FROM NEAR PALOUSE, WHITMAN COUNTY.
W. R. BLOOR, Analyst.

Silica (SiO_2)	46.13	58.77
Alumina (Al_2O_3)	37.36	30.28
Iron (Fe_2O_3)	2.20	1.60
Lime (CaO)	0.65	0.34
Magnesia (MgO)	0.64	trace
Alkalies (K_2O, Na_2O)	trace	0.08
Moisture (H_2O)	1.34	0.88
Loss on ignition	12.20	8.44
Total	100.52	100.39
Total fluxes	2.84	1.68

It was not possible, even under the microscope, to recognize the different minerals in this clay. The largest grains observed had a diameter of about .025 of a mm., while there were many that were about .0125 of a mm. in diameter. There were myriads of individuals, however, that were about .005 of a mm. and less in diameter. All of these grains are colorless.

The chemical analyses of this clay show that it is low in silicia and very low in total fluxes. Its chemical composition, together with its physical properties, make it especially well suited for certain purposes.

Description of the Plant.—The plant is equipped with one pair of rolls for pulverizing the clay, one auger stiff mud brick and tile machine with a capacity of 42,000 brick a day. There is also an automatic wire cutting table in connection with the brick machine. There is one long horizontal pug mill for mixing and tempering the clay for the brick and tile machine, and one hand power repress for brick and roofing tile.

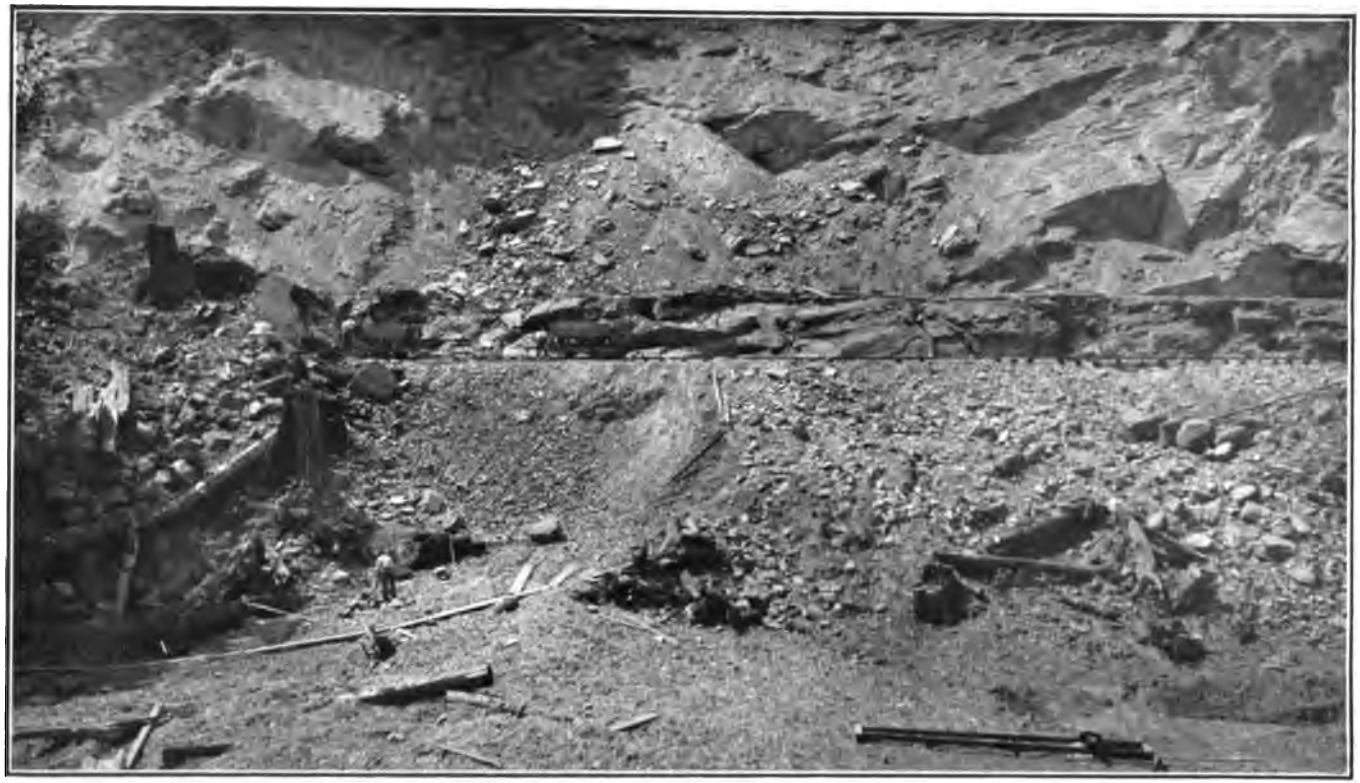
There are three jolly wheels used in molding various kinds of stoneware, one potter's turning wheel, and one wet pan or chaser mill for tempering the clay to be used in the manufacture of the various kinds of stoneware. The main building is 40 by 100 feet, two stories high, and steam heated, both floors being used as dry rooms. There is also an ell 25 by 100 feet in which the machinery is located.

The power for operating the machinery is supplied by a sixty horse power boiler and engine.

The ware is all burned in circular, down draft kilns, there being two of these that are each twenty feet in diameter and one that is only ten feet in diameter.

This company manufactures fire brick, roofing tile, drain tile, sewer pipe, flower pots, stoneware of various kinds, and common and repress building brick.

A sample of clay was received from Mr. G. W. Peddycord of Palouse, but no examination was made of the deposit from which it came. It is light in color, has good plasticity, and appears



S. Shedd, Photo. PAVING BRICK SHALE, DENNY-RENTON CLAY AND COAL COMPANY, RENTON

to be a good clay. The following chemical analysis shows the composition of this sample:

ANALYSIS OF CLAY FROM PALOUSE, WHITMAN COUNTY.
W. R. BLOOR, Analyst.

Silica (SiO_2)	53.16
Alumina (Al_2O_3)	30.06
Iron (Fe_2O_3)	1.83
Lime (CaO)	0.43
Magnesia (MgO)	0.24
Potash (K_2O)	1.50
Soda (Na_2O)	0.09
Titanium (TiO_2)	1.50
Moisture (H_2O)	1.70
Loss on ignition	9.76
Total	100.29
Total fluxes	5.59

This analysis would indicate that this is a very fair grade of clay. The amount of alumina and silica is about the same as in the other samples from Palouse, but the total fluxes is a little higher. The amount of iron is so small that the burned ware should be light colored. It would probably be semi-refractory.

COLFAX.

A brick yard is operated at Colfax where the ordinary basaltic clays are used. The plant is operated during the summer only and mainly, at least, to supply the local demand. The stiff mud process is used and the brick are made on an auger stiff mud machine with a hand power wire cutting table. The brick are all dried in the open air and burned in ordinary scove kilns. A very good grade of common building brick is made here.

PULLMAN.

Basaltic clays suited to the manufacture of building brick are found at Pullman and a yard has been operated intermittently for a number of years. The clay around here in general is a little too fat to make first class brick unless it is very carefully handled. The brick have a tendency to crack more or less in drying and burning and on account of this have to be dried very slowly. The clay around Pullman has good plasticity and a very good tensile strength and should allow a considerable

amount of sand to be mixed with it and not injure these properties seriously. The main difficulty, however, with this is the fact that sand is hard to obtain in this locality, or at least in connection with the clay.

Common building brick and repress facing brick have been made from these clays at different times simply to supply the local demand. The repress brick are fairly smooth and regular. The clay burns to a good brick red color and gives a fairly hard product.

The only yard that is being operated at the present time is about two miles southeast of town. The stiff mud process is used here and the brick are dried in the open yard. They are all burned in the ordinary scove kiln. The yard is operated only during the dry season and to supply the local demand.

GARFIELD.

At Garfield the basaltic clays are used in the manufacture of common building brick to supply the local demand. There is only one small yard there and this is operated only during the dry season of the year. The brick are made on a stiff mud auger machine, dried in the open air, and burned in the ordinary updraft scove kiln.

At many of the small towns throughout Whitman county these basaltic clays have been used at one time or another for the manufacture of common building brick, but so far as the writer is aware these are the only places where yards are in operation at the present time.

The question of fuel is a very important one in the manufacture of brick or any kind of clay products in Whitman county. There is but very little timber in the county; fuel for burning the clays has to be shipped a considerable distance, and this makes it expensive and has a tendency to make the cost of manufacturing brick in the county high.

Columbia County.

Columbia county is one of the southern counties of the state and well toward its eastern border. The principal rocks, if not

the only ones in the county, are basalts, so that the probabilities of finding anything except the residual clays formed from the decomposition of these basalts are not very good. The basaltic clays are quite common throughout the county but are being utilized at but few places.

DAYTON.

Dayton, the principal town in Columbia county, is situated near its center. It may be reached either over the Northern Pacific Railway from Walla Walla or over a branch line of the Oregon Railway and Navigation Company from Bolles. There is one brick yard in operation at Dayton. The clay being used at this place has been formed by the decomposition of the basalt. The deposit is worked to a depth of about six feet. It is worked by means of an open cut without any surface stripping. The upper part of the bank is dark colored on account of the organic matter that it contains. The clay at the bottom of the cut is practically free from organic matter and has a yellowish color. Three samples of this clay were obtained, one representing the upper third of the bank, another the central part, while the third sample was from the bottom of the bank.

Laboratory Examination.—The sample from the top of the bank had a very dark brown color and had but little plasticity. It absorbed water and slaked readily, breaking into small particles. It required 27.5 per cent. of water to temper it to its most plastic condition and had an air shrinkage of 5 per cent. It dried rapidly and without warping or cracking and had a minimum tensile strength of 50 pounds to the square inch, a maximum of 71 pounds, and an average of 59 pounds to the square inch. When heated to the fusing point of cone .010 (950 deg. C.) it had a fire shrinkage of 1 per cent., but was not vitrified and was still soft. After having been heated to the fusing point of cone .05 (1,050 deg. C.) it had a good brick red color but was not vitrified. It had, however, a fair degree of hardness. It completely fused at cone 6 (1,250 deg. C.), having a very smooth and glossy surface, and was dark brown in color.

The sample taken from two to four feet from the top of the bank had much less organic matter and hence was much lighter in color. It slaked quickly, breaking into small particles. While this sample was more plastic than the other still the amount of plasticity was not very great. It dried quickly without cracking or warping and required 24.5 per cent. of water to temper it to its most plastic condition. It shrank 4.33 per cent. in drying and when burned at the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of .8 per cent. After burning at this temperature it was light red in color and not very hard.

When burned at the fusing point of cone .05 (1,050 deg C.) it became a dark brick red in color and was fairly hard. It was not vitrified, however, at this temperature. At the fusing point of cone .01 (1,130 deg. C.) it had become soft enough so that under slight pressure it began to lose its shape. This sample was completely fused at cone 8 (1,290 deg. C.), was a dark brown in color, and had a fairly smooth surface.

This clay showed a minimum tensile strength of 64 pounds to the square inch, a maximum of 94 pounds, and the average of all the briquettes tested was 82 pounds to the square inch. The sample tested showed no signs of cracking or warping in burning.

The sample taken from the lower part of the bank was practically free from organic matter and was yellow in color. It was more plastic than either of the others and worked better. It had a minimum tensile strength of 54 pounds to the square inch, a maximum of 74 pounds, while the average of all the briquettes tested was 66 pounds to the square inch. This sample required 23 per cent. of water to bring about its most plastic condition, and shrank 4.66 per cent. in drying.

When burned at the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of .83 per cent., and had a good red color, but was still soft. After being heated to the fusing point of cone .05 (1,050 deg. C.) it was dark red in color, was of medium hardness, but had not vitrified. At the fusing point of cone .01 (1,130 deg. C.) it became soft enough so that it

would no longer retain its shape. After heating to this temperature it was dark brown in color and had a smooth, glossy surface. It completely fused at cone 7 (1,270 deg. C.).

This sample absorbed water and slaked readily, breaking into very small particles. It may be dried quickly without warping or cracking and the small samples burned showed no signs of cracking.

The following analyses show the chemical composition of these three samples:

ANALYSES OF CLAY FROM DAYTON, COLUMBIA COUNTY.
W. B. BLOOR, Analyst.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	63.06	63.25	64.52
Alumina (Al_2O_3)	13.00	15.34	14.58
Iron (Fe_2O_3)	5.53	5.91	4.47
Lime (CaO)	2.47	2.34	2.35
Magnesia (MgO)	1.08	1.26	1.50
Potash (K_2O)	1.82	1.50	1.86
Soda (Na_2O)	1.62	1.31	1.78
Titanium (TiO_2)	1.30	1.20	1.15
Moisture (H_2O)	2.68	2.63	1.70
Loss on ignition	6.58	3.96	3.57
Chromium (Cr_2O_3)	0.04	0.09	2.53
Phosphorus (P_2O_5)	0.25	0.17	
Sulphur (SO_3)	0.15	0.43	
Strontium (SrO)	0.40	0.16	
Barium (BaO)	0.04	trace	
Zirconium (ZrO_2)	0.10	0.19	
Vanadium (V_2O_5)	0.06	0.18	
Total	100.15	99.92	100.01
Total fluxes	14.88	14.74	15.64

I. Surface sample.
II. From two to four feet below the surface.
III. Lower yellow clay.

The above analyses show this deposit to be very uniform from top to bottom. The larger loss by ignition of No. I is due, mainly at any rate, to the fact that it contains a considerable amount of organic matter. The total amount of fluxing substances in all of these samples is high. The amount of iron is sufficient to give the burned ware a dark red color.

In actual practice these three clays are mixed and used in this way. In fact there is no sharp line separating one from the other, but the dark, almost black, surface material gradually grades into the yellow clay at the bottom of the workings, and the bank from top to bottom, is used for brick.

Garfield County.

Garfield county is situated in the southeastern part of the state and the country rock throughout the county is practically all, if not all, basalt. The county is sparsely settled and the local demand for clay products is very small.

POMEROY.

This is the county seat of the county and practically the only town in it of any importance. Pomeroy is the terminus of a branch of the Oregon Railway and Navigation Company's line that leaves the main line of the company at Starbuck. A small brick yard is operated at times at Pomeroy, the clay that is used being simply surface material and not of very good quality. It is a light grayish colored material, has a low specific gravity and but little plasticity. The soft mud or slop process is used for making the brick and they are burned in the ordinary scove kiln.

Benton County.

This county is situated in the south central part of the state and is entirely within the Columbia lava area. It is bounded on the north, east and south by the Columbia river and on the west by Yakima county. Good clays are not very abundant throughout the county but in some places clays do occur from which common building brick may be made.

PROSSER.

This town is situated in the eastern part of the county, is on the main line of the Northern Pacific Railway, and on the bank of the Yakima river.

Prosser Brick and Tile Company.—This company operates a brick yard at this place to supply the local demand. The clay that is being used is light gray in color, has a fair degree of plasticity, but when used alone has a tendency to crack in drying and burning. It requires 28 per cent. of water to temper it and has a large amount of shrinkage in drying and burning. It has a very low tensile strength, the highest of the eight

briquettes tested being only 13 pounds to the square inch, the lowest being 8 pounds, while the average is 10 pounds to the square inch.

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM PROSSER, BENTON COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	54.02
Alumina (Al_2O_3)	18.56
Iron (Fe_2O_3)	6.48
Lime (CaO)	1.34
Magnesia (MgO)	1.14
Potash (K_2O)	1.76
Soda (Na_2O)	1.14
Titanium (TiO_2)	1.50
Manganese (MnO)	0.10
Moisture (H_2O)	5.23
Loss on ignition	8.04
Total	100.21
Total fluxes	13.46

The above analysis shows this clay to be a little below the average in silica and alumina of the clays that are used in the manufacture of common building brick, while the iron is a little above the average. (See page 33.)

KENNEWICK.

Kennewick is in the extreme eastern part of Benton county, on the Columbia river. The main line of the Northern Pacific Railway also passes through the town.

Columbia Clay Company.—This company is operating a brick yard at this place to supply the local demand for building brick. The clay found here is very similar to that found at Prosser.

YAKIMA COUNTY.

Yakima county is situated in the south central part of the state and extends on the west to the summit of the Cascade mountains. Over a large part of the county the prevailing rock is basalt. Other formations, however, are found in various parts of the county in greater or lesser amounts. On the whole the county is not very well supplied, so far as known at present, with clays suited for the manufacture of even the cheaper grades

of clay products. The main streams of the county rise in the Cascade mountains and along some of these, alluvial clay deposits are found.

NORTH YAKIMA.

This is the county seat, is situated in the north central part of the county, and is the largest town in it. It is on the main line of the Northern Pacific Railway and hence easily accessible.

Garrett Brothers and Company.—Along the Yakima river in places alluvial clay deposits are found, and one of these has been worked at North Yakima by this company. This bed of clay, where it has been opened up, is not of very great extent. The clay lies at the surface and has a thickness of only about three or four feet. Beneath the clay at this place is a bed of gravel. This appears to be a necessary condition in order to have a clay suitable for brick, as this allows the alkalies that are quite common throughout this locality, to be leached or washed out.

This clay is dark brown in color and contains a large amount of vegetable matter. It has a low specific gravity and but little plasticity. It burns to a good red color and cracks and warps but little in drying and burning. It has only a fair tensile strength on account of its sandy nature. This clay is suitable only for the manufacture of common building brick.

The soft mud process is used and the brick are dried in the open yard, and burned in the ordinary scove kiln. The plant is supplied with one soft mud brick machine with a capacity of from 30,000 to 32,000 brick a day. This yard is operated only to supply the local demand.

GRANGER.

Granger is about twenty miles northeast from North Yakima and is on the Yakima river. A branch line of the Northern Pacific Railway also passes through the town.

Clays are found here that are used in the manufacture of common building brick, and a yard is being operated by Johnson Bros., to supply the local demand. In actual practice more

PAVING BRICK PLANT OF THE DENNY-RENTON CLAY AND COAL COMPANY, RENTON

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or less sand is mixed with the clay to prevent checking and to decrease the shrinkage in drying and burning.

Kittitas County.

Alluvial clays are found in places along some of the streams in Kittitas county. In general, however, they are not of very good quality and in only a few places have they been worked.

ELLENSBURG.

This is the principal town in the county and furnishes a local demand for more or less building brick each year. A bed of alluvial clay found along the Yakima river at this place was worked for a number of years and a fair grade of brick made from it. In 1904, however, this had been abandoned mainly on account of the supply at the place where it had been worked, having been almost exhausted.

Coble and Crawford are operating a small yard using a bed of clay found in the eastern edge of the town. This clay occurs in connection with a ridge of gravel at this place. The extent of this bed is not known, but it is probably quite local. The clay is light yellow in color and the bed where it is being worked has a thickness of about fifteen feet.

The clay is taken from the bank ground in an ordinary rock crusher to break the lumps, then tempered and the bricks molded by hand. They are dried in the open yard and burned in scove kilns. The yard is operated only during the dry season and to supply the local demand for common building brick.

CLEALUM.

Some light yellowish colored clays are found at this place and a small yard is being operated in one edge of town. The extent of the clay deposit around Clealum, however, so far as known is not very great and the clay is not of very good quality. At the yard that is in operation here the brick are all hand molded, dried in the open yard, and burned in scove kilns. The yard is operated to supply the local demand.

Chelan County.

Chelan county is a little north of the central part of the state and extends east from the summit of the Cascade mountains to the Columbia river. In the northern part of the county the rocks are mostly igneous and metamorphic and consist of granites, gneisses and schists and closely related rocks. In the southern and eastern part of the county are some sedimentary deposits. In this part of the county are also found considerable areas of the Columbia lava.

WENATCHEE.

Wenatchee is situated on the main line of the Great Northern Railway and on the Wenatchee river at its junction with the Columbia and is the largest town in the county and furnishes a considerable local market for ordinary clay building material.

Hobson Brothers Brick Yard.—There is one brick yard in operation at this place. The clay that is used is light yellow in color, absorbs water readily and slakes quickly, separating into very fine particles. It is free from particles of any gritty or sandy substance. This clay has good plasticity and is easily worked and molded into various shapes. It requires 31 per cent. of water to temper it to its most plastic condition.

In drying it shrank 7.50 per cent., and when burned at the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of .833 of a per cent. After having been heated to this temperature it was light red in color and was still soft, showing that this temperature was too low to produce a good brick. It was again heated, this time to the fusing point of cone .05 (1,050 deg. C.), when it had shrunk 1.666 per cent. additional, or a total in drying and burning of 10 per cent. After burning at this temperature it had a good color and was fairly hard. It completely fused at the melting point of cone 6 (1,250 deg. C.). The samples used in making the tests dried and burned without any signs of warping or cracking.

The stiff mud process for the manufacture of brick is used at this yard, there being one auger stiff mud machine with a capacity of 20,000 brick each day. The bricks are all dried in

the open air and burned in ordinary up draft kilns. In actual practice some sand is mixed with the clay.

This clay showed a maximum tensile strength of 190 pounds to the square inch, a minimum of 140 pounds, while the average of the eight briquettes tested was 155 pounds to the square inch. This is a very good tensile strength and should insure a very small loss from breakage in handling of the dried ware.

CHELAN.

Chelan is a small town situated in the northeastern part of the county, at the foot of Lake Chelan. It is reached by boat up the Columbia river from Wenatchee to the mouth of Chelan river, and from there a distance of three miles, by stage.

H. E. Dunham Brick Yard.—The clay used here is light gray in color, requires 27 per cent. of water to temper it, and is not very plastic. The tensile strength is low, the maximum being only 55 pounds to the square inch, while the minimum is 38 pounds and the average of the ten briquettes tested is only 48 pounds to the square inch. When heated to the fusing point of cone .05 (1,150 deg. C.) it was light red in color and soft. When heated to this temperature it shrank 3.333 per cent. It completely fused at the melting point of cone 4 (1,210 deg. C.) and was of a dark brown color. When burned at a little higher temperature than the fusing point of cone .05 (1,050 deg. C.) it had a good red color and was fairly hard.

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM CHELAN, CHELAN COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	59.84
Alumina (Al_2O_3)	16.40
Iron (Fe_2O_3)	4.10
Lime (CaO)	5.84
Magnesia (MgO)	0.36
Potash (K_2O)	1.62
Soda (Na_2O)	2.84
Titanium (TiO_2)	1.20
Other constituents	1.32
Moisture (H_2O)	0.74
Loss on ignition	5.51
Total	99.77
Total fluxes	17.28

The above analysis shows this clay to be especially high in the total amount of fluxing substances. The amount of silica is just about the average for ordinary brick clays, while the alumina is considerable below the average for this class of clays. The amount of lime is high and would cause a rapid melting after incipient fusion is once reached. (See page 33.)

There is a large body of clay at this place as it covers a considerable area and has a depth of forty feet. There is from one to two feet of sandy clay at the surface and below this occurs about one foot of yellow clay and below this the balance of the deposit is very uniform in character.

The soft mud process is used here for the manufacture of brick. The yard is equipped with one automatic soft mud machine which has a capacity of about 14,000 brick per day. There is also one hand power repress machine for making repress brick. The bricks are all dried in the open air on pallets and burned in up draft scove kilns.

CHAPTER XIII.

CLAYS AND CLAY INDUSTRY OF WESTERN WASHINGTON.

Within the last few years there has been a very great increase in the demand for clay products, especially throughout this part of the state. The towns and cities throughout the whole of Washington have been growing very rapidly and along with this growth has come a desire for more permanent buildings and improvements of various kinds so that the demand for such things as paving brick, sewer pipes, terra cotta, pressed and ornamental brick of various kinds has very greatly increased. On account of the largest cities and more of them being in western Washington the demand for clay products of various kinds has increased much more rapidly in this part of the state than it has in the eastern.

Clays well suited to the manufacture of paving brick, sewer pipe, terra cotta, and stoneware are known to occur in places in western Washington, while clays suited to the manufacture of the various kinds of building brick are widely distributed. Clays from which fire brick are made also occur in a few places.

The deposits that occur throughout this part of Washington are being worked mainly around the larger cities and there are large quantities of good clays in many places in western Washington that are not being utilized at the present time. As the demand increases, however, many of these will become valuable and will be used in the manufacture of various kinds of clay products.

King County.

King county is situated about the center of the state, north and south, and is the largest producer of clay materials of any county in western Washington. On the east it extends to the summit of the Cascade mountains, on the west to Puget sound. Through the western part of the county the country rock is

almost entirely sedimentary and consists mainly of sandstones, slates, and shales, while in the eastern part in the Cascade mountains igneous rocks of various kinds are common.

The clays throughout this county are of three principal kinds, as far as origin is concerned. (1) Glacial clays; (2) shales and clays that are interstratified with the sandstone, slate and coal; (3) alluvial clays.

During the time when northwestern Washington was glaciated the ice covered at least all of the western part of King county and the glacial clays are found very generally distributed over this part of it. These consist of the fine material that was ground up by the ice, during the time when the glaciers occupied this part of the state, and deposited by streams in the numerous small lakes and ponds that were common throughout the region during the time when the ice was disappearing. These clay beds are very irregular in occurrence and vary much in different places as regards the amount of sand they contain. In places they occur interstratified with gravel and till and the extent of the deposit at any particular place is not easily determined. In many places the beds contain so much sand and gravel that they have no commercial value.

These glacial clays are well suited for the manufacture of common red building brick, hollow brick, drain tile, and clay wares of this general character and are being used for these in many places throughout the county.

In places in King county large deposits of clay and shale are found interbedded with the sandstones and slates in the coal formations. These have been developed in a number of places in the county and constitute one of its very valuable industries. These deposits are known to be very large and in all probability occur in many places where they are not known at present.

These were deposited at the time the coal was forming throughout this part of Washington and were laid down in the same bodies of water in which it was formed. In places these shales and clays contain more or less animal remains, all of which are either fresh or brackish water forms.

This coal bearing formation has been designated the Puget

formation and for a considerable length of time there was a large amount of discussion as to its geological age. This has finally been pretty definitely settled, largely from the study of the fossil plants that are so common in the formation. Based mainly on this evidence it is pretty generally believed at the present time, to be Eocene and these clays and shales would then be of this age.

Clays and shales obtained from the coal formation in King county are used in the manufacture of sewer pipe, paving, fire, and the better grades of building brick.

The streams in King county are in the main rather swift, and have made no very large deposits along their courses and for this reason the amount of alluvial clay in the county is not very great. In some places, however, deposits of this character have been formed, but they are very local and, while they may be of good quality, are not so important as the other classes.

The rocks throughout the county in general are not such as usually form the best grades of clay, such as kaolin, when they decompose. The higher Cascade mountains may be an exception to this, however, as at present the geology of this part of the county has not been very thoroughly studied and the character of the rocks in this part of the range is not very well known.

SEATTLE.

Seattle, being the largest town in Washington, furnishes the best local market for manufactured clay goods and on account of this the value of these goods manufactured in close proximity to the town is greater than that of any other one locality in the state. The very great local demand for building brick has been the means of causing a large number of yards to be established at different points around the town and in the small adjoining towns, so that this phase of the clay industry alone is an important one.

The clays in the immediate vicinity of Seattle are all glacial clays and are used mainly in the manufacture of common building brick to supply the local demand.

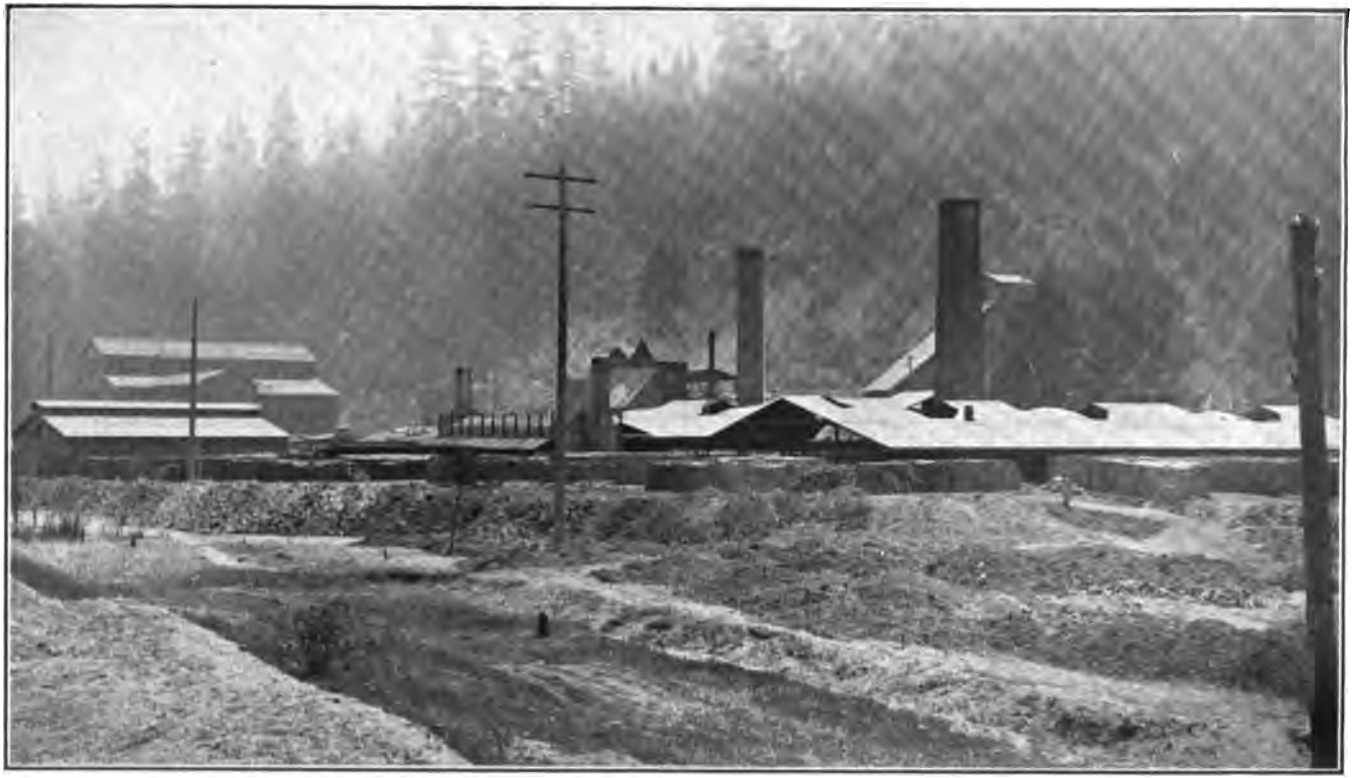
Seattle Brick and Tile Company.—The yard of this company is situated in south Seattle. It is near the main line of the Columbia and Puget Sound Railway, from which a spur extends to the yard so that cars may be furnished for shipping the brick. The clays that are being used at this point are the blue glacial clays of the Puget sound district. The clay bed is worked by an open cut and a vertical face about twenty feet high is exposed. On the surface the deposit has weathered to a yellowish color and shows no stratification. The lower part of the deposit, however, is plainly stratified and in the bank has a distinctly blue color.

This clay at this particular place contains a considerable amount of gravel, in some places the pebbles being of quite good size. The dry clay is gray in color. Two samples of this clay were analyzed and tested, one from the upper part of the deposit, and the other from the lower part.

Laboratory Examination.—The samples from the upper part of the deposit absorb water and slake very quickly, breaking into a mass of small, thin flakes. The clay has a very smooth and slightly greasy feel. It has a low tensile strength, the sample tested showing a minimum of 20 pounds to the square inch, a maximum of only 43 pounds, while the average of the nine briquettes tested is 30 pounds to the square inch.

It has a fair degree, only, of plasticity, but appears to work fairly well. It required 26 per cent. of water to temper it to its most plastic condition, had a shrinkage in drying of 8.36 per cent., and on being heated to the fusing point of cone .010 (950 deg. C.) it had no additional shrinkage. At this temperature, however, it had not vitrified, was light red in color and was still soft. When burned at the fusing point of cone .05 (1,050 deg. C.) it was dark red in color and had a good degree of hardness. It began to soften and lose its shape at the fusing point of cone 1 (1,150 deg. C.) and was completely fused at cone 4 (1,210 deg. C.). After complete fusion it had a smooth surface and a dark brown chocolate color.

The clay from the bottom of the deposit slakes readily, breaking into very fine particles. It is very plastic and works



S. Shedd, Photo. PAVING BRICK PLANT OF THE DENNY-RENTON CLAY AND COAL COMPANY, RENTON

smoothly. It has a medium tensile strength, being somewhat higher than the other sample. It required 26 per cent. of water to bring it to its most plastic condition. It shrank in drying 8.33 per cent., and when burned to the fusing point of cone .05 (1,050 deg. C.) it had an additional shrinkage of 1.67 per cent. After having been burned at this temperature it had a dark red color and was steel hard.

The sample tested dried and burned without warping or cracking.

The following analyses show the chemical composition of this clay:

ANALYSES OF GLACIAL CLAY, SEATTLE, KING COUNTY.

W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.
Silica (SiO_2)	58.96	60.80
Alumina (Al_2O_3)	16.57	18.44
Iron (Fe_2O_3)	6.10	6.00
Lime (CaO)	2.87	3.17
Magnesia (MgO)	2.97	1.34
Potash (K_2O)	0.83	1.32
Soda (Na_2O)	3.24	2.90
Manganese (MnO)	1.15	0.40
Titanium (TiO_2)	0.65	.....
Moisture (H_2O)	3.58	2.10
Loss on ignition	3.36	3.29
Total	99.78	99.76
Total fluxes	17.81	15.13

I. Upper stratified clay.
II. Lower shaley clay.

The above analyses show these two samples to be very similar in composition. They are both of them high in total fluxing substances. The amount of iron in each of them is a little above the average for the common brick clays.

The amount of lime in brick clays, on the average, as shown by Ries* is only about 1.513 per cent., and each of these samples is a little above this, but many clays are being used, however, in which the amount of lime is much greater than this. The large amount of fluxing material causes them to melt at comparatively low temperatures as already shown and the lime in addition to this would cause them to melt with a rather small

*Reis, Geol. Survey of New Jersey, Vol. VI, p. 64.

increase in temperature after they once began to fuse. This clay should, however, make a very good building brick.

Description of the Plant.—The arrangement of the clay bank and the yard at this place is such that the loaded cars carrying the clay run into the upper part of the building which contains the brickmaking machinery. There is a slight down grade from the floor of the clay pit and the loaded cars, when once started, are drawn by gravity to the mill. The clay is first passed through a pair of rolls so arranged that the larger pebbles are thrown out and most of the smaller ones are crushed and the clay ground at the same time.

After passing through these rolls the clay is thoroughly tempered in a pug mill before going to the brick machine. The plant is supplied with two auger machines for making stiff mud brick. These two machines differ in that one is a continuous auger while the other has a revolving shaft to which blades are fastened at certain distances apart and at one end of which there is a short, tapering screw. These blades are so arranged that they force the clay forward through the cylinder in which they revolve until it is caught by the screw and then forced through the die. It is claimed by the president of the company that brick made from this clay on the continuous auger machine are much more laminated than those made on the other type of machine, and on account of this fact the continuous auger machine is not in use at the present time. The machines are supplied with hand power wire cutting tables.

During the dry season the brick are spread out in the open air on the yard to dry, but during the wet season they are stacked inside of dry rooms and these are heated.

The yard is supplied with two large rectangular, permanent down draft kilns. These kilns are built with sloping sides and circular ends and in this way the clamps so frequently used in the case of permanent kilns are dispensed with. Each of these kilns consists of one continuous chamber, and temporary partitions are put across it to form different or separate chambers.

The brick manufactured by this company are not very smooth and contain more or less small pebbles, but they are free from

cracks, and are a good red color, and appear to be hard and strong. This yard is operated during the entire year and manufactures nothing but common building brick which are used in Seattle.

Builders Brick Company.—The Builders Brick Company owns and operates a brick yard in south Seattle only a short distance from the yard operated by the Seattle Brick and Tile Company. This company owns twenty-two acres of land at this place and has a large supply of clay.

At the point where the clay bank has been opened and is being worked there is an exposure forty feet in thickness and as the hill keeps getting higher, farther back from this opening, the thickness will probably keep getting greater. The deposit is worked by means of an open cut, the clay being loaded by means of shovels onto small cars. From the pit the clay is drawn up an incline by means of a cable to the upper part of the mill.

The clay being used by this company is very similar to that used by the Seattle Brick and Tile Company, a little farther south. It is glacial clay with a bluish color, especially when damp, and grayish when dry. The deposit is distinctly stratified, the layers being practically horizontal, and at this point contains less pebbles and gravel than it does in some places.

The clay works very nicely but does not have a very high tensile strength. The amount of shrinkage in drying and burning is not large. It dries and burns with scarcely any warping or cracking and after having been burned has a good red color. This yard is so situated that the brick may be loaded on cars and shipped either over the Northern Pacific Railway or over the Columbia and Puget Sound Railway.

Description of the Plant.—The clay on coming from the bank is first passed through a disintegrator in order to break up the large lumps and to remove whatever gravel there is in it. From the disintegrator it goes to the pug mill where it is thoroughly tempered and from there to the brick machine. The plant contains one auger stiff mud brick machine with a capacity of 40,000 brick a day. There is one hand power cutting table in connection with the brick machine.

The brick are dried in two houses, each 50 by 150 feet, which are heated by means of furnaces, and burned in large continuous down draft kilns. The brick require about three days for drying. The power for driving the machinery is supplied by a 75 horse power electric motor.

This company manufactures common, hollow, and sewer brick, and clinkers and makes about 6,500,000 brick a year.

Hill Brick Company.—The yard operated by the Hill Brick Company is located at 16th Avenue S. and Lane Street in the city of Seattle. The clay being used by this company is the ordinary glacial clay so common around Seattle. It occurs in a very distinctly stratified condition, the individual layers being very thin and occupying practically horizontal positions. The clay occurs in a low hill and is worked by means of an open cut. The plant is located on the opposite side of the hill from where the deposit is worked and a short tunnel has been driven through the hill and the clay is taken through this on cars.

The clay at this point appears to be fairly free from gravel, to have a fair degree of plasticity, and medium tensile strength. It appears to dry very readily without warping or cracking. The clay works very nicely and smoothly, giving good sharp edges and regular outlines.

In appearance it is very similar to the clay used by the Seattle Brick and Tile Company. When wet it has a bluish color and when dry is light gray.

Description of the Plant.—The plant is equipped with a pair of rolls for grinding the clay, one pug mill for tempering it, and one automatic wire cut auger stiff mud machine, having a capacity of 30,000 brick every seven hours. The bricks, when they come from the machine, are placed on cars and run into the dry kilns. There are eight of these tunnel dryers, each being one hundred feet long. The driers are all heated by means of hot air and a large circular fan is used to produce circulation. The brick are burned in a continuous down draft kiln, which has a capacity of 26,000 brick each day; that is, 26,000 burned brick may be taken out of the kiln each day

and the same number of dry bricks put into it. The kiln is not separated into chambers by permanent walls but by temporary paper partitions which, when a certain temperature is reached, burn out and allow the chambers to connect.

The automatic wire cutting device used at this plant is different from that used in most of the brick plants in Washington. It consists of a revolving wheel so arranged that as the bar of clay issues from the die on the brick machine the wheel revolves and carries the wires, which are fastened to it and which do the cutting, through the bar of clay. The rate of revolution of the wheel and the forward movement of the bar of clay are such that the wire is carried down vertically through the clay.

The bricks made by this company are very free from small pebbles and are quite smooth and regular in shape. They are of very good color and appear to have good strength.

Loshe Brick Company.—This company operates a brick yard in the southwest part of Seattle near the mouth of the Duwamish river. The clay used at this yard is the blue glacial clay and is very similar to that being used in other places around Seattle. The clay bank at this point is very free from pebbles. The bank is worked by means of an open cut and about thirty feet in depth of clay is exposed in the face of the workings. The clay, however, is deeper than this, as the bottom of the deposit is not exposed in the present workings. There is undoubtedly a large body of clay at this point.

The deposit is not uniform throughout its entire thickness, but in places it contains a considerable amount of sand, while in others it is very fat and plastic. In actual practice the sandy and fat clays are mixed in certain proportions and better results obtained than by using either alone. The fat clay by itself has a large amount of shrinkage and when dried rapidly would have a tendency to warp and crack, and a certain amount of the sandy clay mixed with it would overcome both of these.

The clay at this place is very distinctly stratified and has a very gentle dip to the southwest.

Description of the Plant.—The stiff mud process is used at this yard and there is one auger stiff mud brick machine, having a capacity of 30,000 brick every ten hours. The pug mill for tempering and mixing the clay is attached direct to the brick machine and in this case is really a part of it. There is one hand power wire cutting table in connection with the brick machine.

At the present time all of the brick are dried in the open yard but it is the intention to construct at once steam heated tunnel driers of sufficient capacity to dry 30,000 brick every ten hours. There is one continuous kiln 50 by 150 feet in size and capable of handling about 30,000 brick a day. This kiln has fourteen chambers. These, however, are not separated from each other by permanent partitions, but instead of this when a chamber is filled a temporary paper partition is put between it and the next one. The kiln is of the down draft pattern.

The machinery is driven by steam, there being a 50 horse power boiler and a 35 horse power engine. The brick made here appear to be of very good quality, and are of good color, free from cracks and of good strength. They are hauled by teams and delivered in different parts of Seattle.

Abrahamson Yard.—The brick yard of Mr. A. Abrahamson is situated in the southwest edge of Seattle near the mouth of the Duwamish river and is a short distance south of the Loshe Brick Company's yard. The clay at this point is the same blue glacial clay and is very similar to that used at the Loshe yard. The deposit here is worked in much the same way that it is in the other yards around Seattle, the main difference being that it is loaded onto the small cars, on which it is conveyed to the plant, by means of a steam shovel. The clay is exposed in the workings for a depth of about fifty feet. It is not perfectly uniform, however, for this entire depth, being in some places more sandy than it is in others. These different grades are all mixed and used in the manufacture of the different kinds of brick made at this yard.

The clay works very nicely and dries and burns without warping or cracking, and burns to a good color.

Description of the Plant.—There is one auger machine that is claimed to have a daily capacity of 100,000 brick. About 80,000 brick a day are actually made. This is what is known as a combined machine, the pug mill for mixing and tempering the clay being a part of the brick machine. It also has an automatic wire cutting attachment and two pairs of crushing rolls for grinding the clay before it goes to the brick machines.

The plant is supplied with a five tunnel, steam heated drier and also a long shed in which some of the brick are dried. They are burned in a continuous down draft kiln 48 by 140 feet in size and containing sixteen chambers. The kiln has a capacity of about 25,000 brick every ten hours. When one chamber has been burned and cooled the brick are removed and then it is filled again and a temporary paper partition put in between it and the next empty chamber and this one is filled. While this is being done in one part of the kiln the brick in the other parts are in the various stages of burning and cooling.

The machinery is driven by steam, there being two large boilers and a 100 horse power engine for the brick machinery and a 14 horse power engine to run a dynamo which furnishes electric lights for the plant. The boilers also furnish steam to heat the driers.

Common building, hollow, and sewer brick as well as some drain tile are made at this yard. About 6,000,000 brick are made in a year.

Washington Brick and Tile Company.—The brick yard operated by this company is on the Duwamish river a short distance south of the yard operated by Mr. A. Abrahamson. The clay used by this company is blue glacial clay similar to that used in a number of the yards around Seattle. The deposit is opened by means of a surface pit or open cut. The clay is stratified, the layers being practically horizontal. About twenty feet in thickness of this clay was shown in the workings. The deposit, however, is thicker than this, as only the upper part of it is being used. The deposit at this point is very free from gravel.

The clay on coming from the bank is first passed through a

pair of rolls and pulverized, after which it goes to the pug mill and is tempered to the proper consistency for a stiff mud brick. The plant is supplied with one automatic wire cut auger stiff mud brick machine which has a capacity of about 50,000 brick a day. The brick at this yard are dried in the open air and burned in ordinary up draft kilns.

The clay at this point works very nicely and drys and burns without much warping of cracking. The brick are of good color and have good tensile strength.

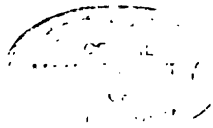
Pontiac Brick Company.—The Pontiac brick yard is about two miles from the northern part of Seattle on the western shore of Lake Washington. It is also on the line of the Northern Pacific Railway that connects Seattle and Bellingham, and a sidetrack has been built from the main line to the yard. The clay being used at this place at the time the writer visited the yard (July, 1906) appeared to be a slide and it was not possible to tell very much about the deposit. In all probability, however, as soon as this surface material has been used the blue glacial clay will be found.

Description of the Plant.—The plant is supplied with one pair of conical rolls for removing the pebbles from the clay. There is also one disintegrator for pulverizing the clay. There are also two crushers that are used for this same purpose. The stiff mud process is used at this place, the clay being tempered on a short pug mill and the brick made on a stiff mud, wire cut auger machine, said to have a capacity of 80,000 brick in ten hours. About 30,000, however, are actually made in a day.

The brick are dried in a number of different ways at this yard. About one-third of them are placed on top of the kiln and the heat from the burning kiln utilized for drying them. There is a steam heated drier which has a capacity of 8,000 brick a day in which a part of the brick are dried. During good weather especially, a considerable part of the output of the plant is dried under open sheds on the yard.

This yard is equipped with a system of overhead trolleys for conveying the brick from one place to another on the yard. As the brick come from the machine they are stacked on boards

Kinsey, Seattle, Photo PLANT OF THE DENNY-RENTON CLAY AND COAL COMPANY AT VAN ASSELT



about ten inches wide and three feet long. These boards are known as pallets. After these pallets have been loaded with brick they are taken by means of this system of overhead trolleys and conveyed by a small boy to any part of the yard and the pallets deposited and the brick left on the pallets while drying. When the brick are dry they are carried to the kiln also by this same trolley system.

The brick are burned in a continuous down draft kiln. At this plant a short stack is used and artificial draft in place of the tall stack and natural draft which is commonly used for burning brick. A large fan connected with the kiln is used to produce the draft.

Steam power is used for operating the machinery and is supplied by a large boiler and engine. Only common building brick are made by this company.

RENTON

Renton is about twelve miles southeast of Seattle and is on the line of the Columbia and Puget Sound Railway. There is also a branch line of the Interurban Railway, which is an electric road between Seattle and Tacoma, that has its terminus at this point. These roads give very good shipping facilities to or from this place.

Around Renton are deposits of sandstones, shales, and slates which belong to the Puget formation along with which are extensive beds of coal and coal mining is one of the principal industries of the town.

Denny-Renton Clay and Coal Company.—This company has one of its clay working plants located at Renton. This plant is the largest brick plant in Washington and the only one, so far as the writer knows, where paving brick are being made. The clay which occurs here belongs to the Puget formation and to the Eocene period. This material is a light gray colored shale which occurs interbedded with the sandstone, slate and coal of the coal formation. The amount of this material in this locality is very great. At the point where this deposit has been developed by this company a thickness of about a hundred and fifty feet is being used. This, however, does not represent the

thickness of the deposit as it continues below the present workings.

The shale at this point shows distinct stratification and the formation lies very flat, almost horizontal. It outcrops upon a hillside and the clay is broken down by blasting. The different layers vary a little in color and texture, some being coarser grained than others but in actual practice they are mixed and all used. Above the layer of shale is a gravel which varies more or less in thickness but is usually about six to ten feet. This gravel has to be removed and this is done by sluicing. Coal occurs here also and is mined and used for fuel in the burning of the clay.

Laboratory Examination.—This material is fine grained and very plastic when mixed with water and capable of being molded into almost any shape desired. It required 23 per cent. of water to bring it to its most plastic condition, had a shrinkage of 6.666 per cent. in drying, and when heated to the fusing point of cone .05 (1,050 deg. C.) it had shrunk no more. It did not vitrify, however, at this temperature and was not as hard as it should be, showing that it should be burned at a somewhat higher temperature. The color also showed under burning as it was a little light. It completely fused at the melting point of cone 6 (1,250 deg. C.) and had a very dark color.

This clay showed a maximum tensile strength of 312 pounds to the square inch, a minimum of 250 pounds, while the average of the eight briquettes tested was 280 pounds to the square inch. This is a good high tensile strength.

The following chemical analysis shows the composition of this shale

ANALYSIS OF SHALE FROM RENTON, KING COUNTY.

C. C. TODD, Analyst.

Silica (SiO_2)	62.11
Alumina (Al_2O_3)	17.59
Iron (Fe_2O_3)	4.77
Lime (CaO)	1.58
Magnesia (MgO)	2.26
Potash (K_2O)	2.30
Soda (Na_2O)	1.65
Titanium (TiO_2)	0.51
Moisture (H_2O)	1.63
Loss on ignition	5.60
Total	99.95
Total fluxes	13.02

The composition of this shale is very close to that of the average of vitrified brick shale as shown on page 23. The silica is a little higher, the alumina and iron a little below the average, while the total fluxing substances is the same. This shale has both the chemical and physical properties to make it especially well adapted for high grade paving brick. The brick manufactured from this shale are dark red in color, very hard, tough and compact.

The following tables showing the results of physical tests made on the Denny-Renton paving brick were kindly furnished by the city engineering department of Seattle:

CROSS BREAKING STRENGTH OF DENNY-RENTON PAVING BRICK.

Date.	Number.	Make and Quality.	Cross Section of Middle.		Distance Between Supports.	Breaking, Total Pounds.	Force Lbs. per Sq. in. by Cross Section.	Area in Sq. in.
			Thickness.	Width.				
1906 Sept. 15	Set No. 1. 1	Denny-Renton Co. No. 1 Pavers from 3rd Ave. between James and Cherry	2.48	4.15	6 inch	9,395	938.00	10.10
	2		2.40	4.12	"	7,970	805.00	9.90
	3		2.36	3.90	"	10,550	1,147.00	9.20
	4		2.45	4.05	"	9,840	998.00	9.90
	5		2.42	4.06	"	6,755	688.00	9.82
	6		2.45	3.86	"	10,110	1,065.00	9.48
	7		2.39	4.02	"	8,395	874.00	9.60
	8		2.36	4.06	"	11,245	1,174.00	9.58
	9		2.39	4.05	"	7,565	782.00	9.67
	10		2.38	4.13	"	12,585	1,277.00	9.85
	Average. ...		2.40	4.04	.....	9,441	974.30	9.70
Average Modulus of Rupture 2,170 lbs. per sq. in.								
1906 Sept. 15	Set No. 2. 11	Denny-Renton Co. No. 2 Pavers from 3rd Ave. between James and Cherry.	2.46	3.90	6 inch	9,455	985 00	9.60
	12		2.52	4.00	"	5,285	528.00	10.08
	13		2.47	3.92	"	10,415	1,076.00	9.68
	14		2.39	4.08	"	8,135	887.00	9.72
	15		2.41	3.90	"	9,985	1,057.00	9.39
	16		2.40	3.94	"	10,785	1,185.00	9.46
	17		2.45	3.95	"	8,375	868.00	9.65
	18		2.41	4.01	"	7,650	793.00	9.65
	19		2.39	4.08	"	7,750	795.00	9.75
	20		2.48	3.82	"	9,615	907.00	9.50
	Average.....		2.44	3.96	.....	8,630	897.60	9.65
Modulus of rupture 2,030 lbs. per sq. inch								
1907 Nov. 15	*6	Denny-Renton.	2.40	4.10	6 inch	10,450	1,062.00	9.84
	†7		2.42	4.12	"	10,455	1,061.00	9.85

Modulus of Rupture No. 6, 2,331; No. 7, 2,230 per sq. inch.

*Selected by the company.

†Selected by Mr. Corey.

Tested at the University of Washington testing room, Mr. Phelan in charge. Present for the city: Mr. W. L. Thompson, Mr. Corey, Mr. C. J. Moore; for Denny-Renton Company, Mr. Crow, Mr. Mitchell, Mr. Geijbeck.

Brick set on edge: Set No. 1: Set No. 2: :1 :1.002106.

Modulus of Rupture computed from:

$$F = \frac{3WL}{2BD^2} \text{ in which}$$

F = Mod. of Rupture in lbs. per sq. in.
W = Total load in pounds
L = Length of span = 6 in.
B = Breadth of brick in inches
D = Depth of brick in inches.

In the above table set number one is considered by the company as No. 1 Pavers and so designated by them, while set number two is designated as No. 2 Pavers. The table, however, shows but little difference between them.

RATTLE TEST OF DENNY-RENTON PAVING BRICK.

DATE	BRAND.	LOCATION.	LOT.	600 REVOLUTIONS	
				No. Brick.	Loss per ct.
1905					
Nov. 17	Denny-Renton	Pike between 7th and 8th.....	1	22	19.0
1906					
Feb. 24	" "	Denny Clay Co.'s.	1	22	10 3
Feb. 24	" "	" "	2	22	6.6
1905					
Sept. 12	" "	" "	1	22	18.7
Sept. 12	" "	" "	2	22	12.7
1906					
Apr. 16	" "	3d and Union.....	1	22	8.8
Sept. 10	" "	3d and James.....	1	22	10.0
Average.....					10.3

ABSORPTION TEST ON DENNY-RENTON PAVING BRICK.

DATE.	BRAND.	LOCATION.	Description.	No.	ABSORPTION PER CT.		Sp. Gr.
					1 Day.	3 Days.	
1905							
Sept. 18	Renton Pav.	....	.....	1	.58	.....	2.39
"	" "	....	.....	2	1.16	.....	2.36
Sept. 12	Denny-Renton	From Denny Clay Co.	.....	1	.28	.42	.....
"	" "	....	.....	2	.29	.86	.....
Nov. 17	" "	Pike bet. 7th and 8th.	.....	1	3.77	3.51	.....
"	" "	" " " " " "	.....	2	1.14	1.56	.....
1906							
Feb. 13	" "	Denny Clay Co.	.....	1	.41	.55	2.41
"	" "	" " " "	.....	2	.54	.82	2.38
Mch. 30	" "	Common St. (2 culls)	Light color	1	3.07	3.20	2.33
"	" "	" " " "	" "	2	2.16	2.16	2.38
Apr. 16	" "	From 3rd and Union..	Dark "	1	.....	2.76	2.29
"	" "	" " " "	" "	.....	.....	.....	.....
"	" "	" " " "	Light "	2	.....	5.07	2.18
"	" "	" " " "	" "	3	.....	.43	2.37
"	" "	" " " "	" "	4	.....	.29	2.24
Sept. 10	" "	From 3d and James...	" "	1	3.52	3.96	2.25
"	" "	" " "	" "	2	3.73	4.03	2.24
"	" "	" " "	" "	3	1.74	2.18	2.34
Oct. 5	" "	7th and Pike.	.....	1	2.08	2.66	2.29
"	" "	" " "	.....	2	3.01	3.38	2.26
"	" "	" " "	.....	3	3 95	4.26	2.21
Average.....					1.96	2.33	2.31

Description of the Plant.—The shale on coming from the bank goes into two large storage bins. From these it is taken as needed and first passed through a jaw crusher which breaks all the large lumps. It then goes to the dry pans, of which there are four large ones, where it is thoroughly pulverized and then screened, after which it is conveyed to storage bins until needed for use.

There are two large horizontal pug mills for mixing and tempering the clay, two auger stiff mud machines, one having a capacity of 30,000 and the other 75,000 brick every ten hours. These machines are each of them supplied with automatic end wire cutting attachments. This plant is also supplied with one dry press brick machine which has a capacity of 20,000 brick in ten hours. There are also four repress machines for repressing paving brick.

The brick are all dried in tunnel driers, there being twenty of these, each a hundred and ten feet long. These are heated by what is known as the waste heat system, the heat from the cooling kilns being utilized for this purpose. There are nine circular kilns, each thirty-four feet in diameter, and five square

kilns with a capacity of 200,000 brick each, giving a total kiln capacity of about 2,000,000 brick. The main building is 145 by 175 feet, four stories high. The machinery at this plant is all driven by electricity, eight motors being used for this purpose, ranging from 10 to 150 horse power.*

The company manufactures at this place vitrified building, paving, and dry press facing brick. These are used very extensively in Seattle and are also shipped to various other places throughout the west.

VAN ASSELT

Van Asselt is situated a short distance south of Seattle on the Northern Pacific Railway and the Columbia and Puget Sound Railway. The electric line from Seattle to Tacoma also passes through it. On account of its location it is very easy of access and has good shipping facilities.

Denny-Renton Clay and Coal Company.—This company has one of its large clay working plants located at Van Asselt. There is no clay occurring at this place and all that is used by this company in the plant here is shipped in on cars from various places. This plant is a large and well equipped one and has been in operation for a number of years. The principal products made here are sewer pipe and terra cotta. Some paving brick and fire brick are also made at this place.

The different kinds of clay when they arrive at the plant are stored under sheds, each kind being kept by itself. These clays come principally from Taylor and Kummer.

The clay is first passed through a jaw crusher where all of the larger lumps are broken. From the crusher the clay is conveyed to the dry pans and the grinding completed. The plant is supplied with two of these dry pans for pulverizing. After the clay is pulverized it goes into storage bins ready for use. The plant is supplied with three wet pans for use in tempering the clay for sewer pipe and terra cotta. There are also two

*Since the above description of this plant was written it has been very much enlarged by the addition of more brick machines, seven new rectangular kilns having a capacity of 320,000 brick each, and much new dry kiln space. These additions make this an especially large plant.

pug mills that are used to mix and temper the clay for the brick machines.

There is one auger stiff mud brick machine which has a capacity of 45,000 brick every ten hours. This also has an automatic wire end cutting machine with a capacity of 24,000 brick a day. There are two sewer pipe machines on each of which various sized pipes, up to those that are thirty inches in diameter, may be made. There is a six tunnel steam heated drier in which the brick are dried. These tunnels are each one hundred feet long and the total capacity of the drier is about 75,000 brick. The temperature in these tunnels at the end where the brick enter is 75 deg. F. while it gradually increases toward the exit where a temperature of 200 deg. F. is reached.

All of the ware made here is burned in circular down draft kilns of which there are thirteen, each having a diameter of thirty feet. The paving brick require about ten days to burn while the sewer pipe burns in about six days. The main building is 80 by 200 feet in size and three stories high. This building is steam heated throughout and a considerable part of it is used as drying rooms for the sewer pipe. These are placed on end on the floor and dried from three to six days. The temperature in this building is maintained at about 160 deg. F. during the night but is much lower than this during the day time.

The terra cotta works are in a separate building 100 by 150 feet in dimensions. This building is also steam heated. The drafting, designing, making the molds, and molding the terra cotta are all done in this building.

There are two engines for driving the machinery, one being a 150 horse power and the other 140 horse power. There are five boilers which furnish the steam for the engines and also for heating the drying tunnels and the buildings. The fuel used here is coal which is supplied from the company's own mines.

The principal products being made at this plant are sewer pipe and terra cotta. The sewer pipe is all salt glazed.

KUMMER

Kummer is situated about thirty miles south and east of Seattle on Green river. There is a spur track, from the main line of the Columbia and Puget Sound Railway near Franklin, to this place which furnishes good shipping facilities. Large deposits of clay occur at this place, some of which have been developed and worked for a number of years past by the Denny Clay Company.

Denny-Renton Clay and Coal Company.—This company is the successor to the Denny-Renton Clay Company and now operates the clay and coal mines at Kummer. No clay products are manufactured at Kummer, the clay mined here being shipped to the plant at Van Asselt.

A large part of the surface materials around Kummer are glacial deposits of gravels, sands and tills. Underneath these are beds of sandstones, shales, slates and coal. Green river rising high up in the Cascade mountains has cut a deep canyon along a considerable part of its course. At Kummer it has cut through the glacial material which occurs on the surface and deep into the sedimentary deposits beneath and exposed them along the canyon. At Kummer this canyon is about 250 feet deep.

The clays that occur at Kummer are of a hard shaley nature and occur interbedded with the sandstones and coal and all belong to the Puget formation.

These beds where they are worked at Kummer have a dip of about 50 deg. to the east. The following section across the clay and coal beds at the mine of the Denny-Renton Clay and Coal Company was furnished by Mr. Ward Harris at the time when he was superintendent for this company at Kummer:

SECTION AT CLAY AND COAL MINES AT KUMMER.

	Ft.
Sandstone	
Impure Coal	3
White Clay	1
Fire Clay	7
Impure Coal	4
Sewerpipe Clay	60
Good Coal	6
Shale and Clay	60

PLANT OF THE DENNY-RENTON CLAY AND COAL COMPANY AT TAYLOR

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	Ft.
Impure Coal	3
Sandstone	72
Impure Coal	3
Good Coal	4
Sandstone	135
Sewerpipe Clay	10
Impure Coal	3
Sandstone	65
Impure Coal	3
Sewerpipe Clay	35
Impure Coal	4
Impure Clay	16
Pure Coal	2
Sewerpipe Clay	

This company mines at this place, coal, fire clay, sewerpipe clay, and a pure white sand that is used in the manufacture of fire brick. The amount of clay here is very large the deposits being extensive and, as shown above, having great thickness. The deposits are worked by the common coal mining methods, the pillar and stall scheme being used and the coal and clay worked from one main tunnel.

The main tunnel starts from a point in Green river canyon twenty feet above high water mark and from this latterals have been driven as needed in order to reach the clay or coal. The clay appears to stand up well and allows of its being worked in very large breasts with very small pillars. In the case of the sewerpipe clay, especially, it is worked in very large rooms and the supports are far apart. The clay is taken to the top of the hill over a very steep incline, which is about 700 feet long, and dumped into bunkers ready for loading onto cars to ship to Van Asselt.

The fire clay which occurs here is very dark, almost black in color and of a flinty nature. It has a very smooth feel, breaks with a characteristic conchoidal fracture, the pieces usually having rather sharp edges. It will not slake in water and when ground has practically no plasticity and very low tensile strength.

It required 28 per cent. of water to make it so it could be molded into any shape at all and shrank 5 per cent. in drying. When heated to the fusing point of cone .05 (1,050 deg. C.) it had an additional shrinkage of 3.33 per cent. After heating

to this temperature the color had changed to almost a white. The grains had not cemented together and it was very friable and could be easily pulverized between the fingers.

The following analyses show the composition of this clay:

ANALYSES OF FLINT FIRE CLAY FROM KUMMER, KING COUNTY.
W. B. BLOOR, Analyst.

Silica (SiO_2)	40.37	40.26	33.44*
Alumina (Al_2O_3)	38.57	35.84	45.23
Iron (Fe_2O_3)	2.43	2.20	1.57
Lime (CaO)	0.67	0.40	1.60
Magnesia (MgO)	0.45	0.26	3.61
Potash (K_2O)	0.08	.....	1.44
Soda (Na_2O)	0.22	trace	
Titanium (TiO_2)	.....	2.38	.....
Moisture (H_2O)	1.56	1.75	.....
Loss on ignition	15.80	15.21	16.44
Total	100.65	99.30	103.33
Total fluxes	4.85	6.24	8.22

The above analyses show this clay to be very low in silica and in fact much lower than is found in most of the best fire clays that are being used throughout the country. The percentage of alumina on the other hand is very high. The effect of both of these condtitions would be to tend to make this clay very refractory.

Free silica or quartz at high temperatures acts as a flux so that other things being equal the clay with the least amount of quartz should be the most refractory.

The total amount of fluxing substances shown by these analyses is higher than that of most good fire clays, the iron especially being high. One of the analyses shows a very high percentage of titanium also while another shows a large amount of magnesia. Each of these substances are strong fluxes and would tend to lower the fusion point of this clay. This, however, would be partially at least overcome by the low percentage of silica and high percentage of alumina. The percentage of the alkalies and lime is not large and the composition of this clay on the whole is such that it should resist high temperatures.

A sample of this flint fire clay was tested by Prof. Edward Orton, Jr., Columbus, Ohio, and found to fuse at cone 34.25

*Washington Geological Survey, Vol. I, p. 175. W. J. Rattle, Analyst.

or about 1,820 deg. C. He says this clay has made a very creditable showing as a high grade refractory clay. Anything above cone 32 is regarded as good. There are, however, a considerable number of clays in the United States that will stand cones 35 and 36.

Its physical properties are such, however, that in order to make a satisfactory fire brick some more plastic clay should be mixed with it so as to make it bond and produce a more firm and solid brick.

Most fire brick are made from a mixture of several grades of clay. To make a good bond for the non-plastic flint clays the material should have a small amount of shrinkage. This is necessary so that in burning, the bond between the plastic and non-plastic material may not be broken. On account of this fact, clays high in alumina are as a general thing not well suited for this purpose. The most satisfactory clay is one that has good plasticity and at the same time has more or less of a sandy nature. If such a clay were mixed with this flint clay it would help the bonding and make a firmer and more solid fire brick.

The most important quality of a fire clay is its power to resist a high temperature and not melt and the question of how solid and firm the particles in a fire brick should be held together will depend somewhat on the conditions under which the brick are to be used. Unfortunately, however, the manufacturer usually cannot know where the brick are to be used. If a brick is to be used where it will not be subjected to abrasion then the question of withstanding the required temperature is about the only one that needs to be considered, while on the other hand if it is to be used where it is constantly subjected to more or less abrasion as well as high temperature, then the question of bonding becomes a very important one in determining the length of time the brick will last.

This company has a large body of this flint fire clay and uses it in the manufacture of fire brick, and has very recently discovered on its property at Taylor a plastic clay which is said to be highly adapted as a bond for it and is making fire brick

with the mixture at its Taylor plant, putting it on the market under the trade mark "Renton" Fire Brick.

Large deposits of sewerpipe clays occur at Kummer, also, and these are being extensively mined and the clay shipped to the plant at Van Asselt. The sewerpipe clays occur interbedded in the coal formation and lie above the fire clay which occurs in the same formation. Several of these beds are found here, some of them being as much at least as sixty feet in thickness.

These clays are not so hard as the flint clay and do not break with conchoidal fracture. They are very fine grained and vary in color from those that are very dark, almost black on account of the organic matter which they contain, to those that are light gray.

The sample of this clay used in making the tests, the results of which are given here, was light gray in color, had a very good degree of plasticity, and worked nicely and smoothly. It required 32 per cent. of water to temper it to its most plastic condition, had an air shrinkage of 8.33 per cent. and when heated to the fusing point of cone .05 (1,050 deg. C.) it had an additional shrinkage of 3.33 per cent. At this temperature it was light red in color and was soft. At the fusing point of cone .01 (1,130 deg. C.) it became dark red in color, was steel hard and had a clear metallic ring.

The samples tested showed no signs of melting at this temperature but retained their shape perfectly. They dried and burned without warping or cracking.

Under the microscope it showed a mass of very small grains the largest being about .05 of a mm. in diameter while the larger part of the sample examined was made up of individual grains that were about .02 of a mm. in diameter. There were, however, many grains that were much smaller than this even. The grains are subangular to rounded in outline. Some are clear and colorless but the larger part of them are more or less of a yellowish or brownish color.

The minerals recognized were quartz, feldspar and occasionally small specks of what appear to be magnetite. This clay has some very fine particles of grit in it.

The following analysis shows the chemical composition of this clay:

ANALYSIS OF SEWER-PIPE CLAY FROM KUMMER, KING COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	63.90
Alumina (Al_2O_3)	19.42
Iron (Fe_2O_3)	5.75
Lime (CaO)	0.88
Magnesia (MgO)	1.80
Alkalies (Na_2O, K_2O)	1.81
Moisture (H_2O)	0.76
Loss on ignition	6.40
Total	100.72
Total fluxes	10.24

The above analysis shows this clay to have about the average composition of the clays that are used throughout the country for the manufacture of sewer pipe. The amount of silica is sufficient so that the pipe should take a good salt glaze. The total amount of fluxing substances is not large.

Sewer pipe that are of a chocolate color usually sell more readily and bring a better price in the market than light colored ones. This clay contains iron enough so that the pipe have a good color. The amount of lime is very small which is a point in favor of this clay. As has been shown in Part I of this report, the tendency of lime is to cause the clay to soften very rapidly after the point of incipient fusion is reached so that it becomes viscous with only a few degrees increase in temperature.

Sewer pipe should be vitrified in burning and if a clay contains a large amount of lime it would be difficult, many times at least, to get this result without danger of the pipe softening and losing its shape. Shale which is well suited for the manufacture of paving brick occurs here also and is being used by this company.

This shale is gray in color, is medium hard and very fine grained. It has very little plasticity and hence is not readily molded. When water is added it does not slake and is softened but little. This shale when finely pulverized requires 17.5 per cent. of water to bring about a condition such that it can be molded at all. It shrank 4 per cent. in drying and when burned at a temperature of cone .05 (1,050 deg. C.) it had an addi-

tional shrinkage of 2.5 per cent. At this temperature it had become brick red in color but had not vitrified and in fact was a little under burned. It was completely fused at the melting point of cone 10 (1,330 deg. C.). After fusion it was dark brown in color having changed but little from its original color.

The following chemical analysis shows the composition of this shale

ANALYSIS OF SHALE FROM KUMMER, KING COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	61.58
Alumina (Al_2O_3)	17.46
Iron (Fe_2O_3)	6.69
Lime (CaO)	0.40
Magnesia (MgO)	1.87
Potash (K_2O)	2.80
Soda (Na_2O)	0.78
Titanium (TiO)	0.65
Moisture (H_2O)	1.16
Loss on ignition	7.00
Total	99.89
Total fluxes	12.69

The above analysis shows this shale to be very similar in composition to that from Renton and Taylor. Its physical properties however, are not so favorable. The physical properties perhaps might be improved by weathering and make the shale suited for paving brick.

At Kummer, occurring interbedded with the shales and coal are beds of very soft friable sandstones which are worked by this company. This sand is used at the plant at Van Asselt in the manufacture of certain kinds of clay products. In use it is mixed with the shale in certain proportions in the manufacture of fire brick and acid brick.

The following analysis, taken from Vol. I, p. 175, Washington Geological Survey Report, shows the composition of this sand:

ANALYSIS OF SILICA SAND FROM KUMMER, KING COUNTY.

Silica (SiO_2)	78.60
Alumina (Al_2O_3)	13.08
Iron (Fe_2O_3)	1.22
Iron (FeO)	0.648
Lime (CaO)	2.29
Magnesia (MgO)	0.114
Water (H_2O)	3.30
Total	99.252

The company mines the coal which occurs here in connection with the clay and it is used as fuel for burning the ware and for the boilers at Kummer.

TAYLOR.

Taylor is situated about twenty-five miles almost due southeast of Seattle. It is the terminus of a branch line of the Columbia and Puget Sound Railway which leaves the main line at Maplevalley.

Some of the clays that occur at this place are found interbedded with the sedimentary deposits of the Puget sound formation while others appear to be residual formed from the decomposition of igneous rocks. There are a number of different grades of shales and clays found here and the extent of the deposits is very great.

Denny-Renton Clay and Coal Company.—This company is working these clays and shales and operating a large plant here. The ordinary coal mining methods are used for working these deposits. A long tunnel has been driven into the side of the hill so as to cut these different beds of clay, shale and coal and the deposits worked from this tunnel. These beds dip to the southwest at an angle of about 80 deg. The main tunnel has a length of 1,100 feet and has cut a number of these different clay beds. This tunnel shows the following section:

SECTION IN MAIN TUNNEL AT TAYLOR.

	Ft.
Glacial sediment	10
Sandstone	300
Shale clay	15
Sandy shale	41
Shale clay	16
Sandstone	42
Coal (No. 1)	6
Sandstone	165
Carbonaceous material	10
Coal (No. 2)	3
Shale	18
Carbonaceous material	12
Coal (No. 3)	3
Sandstone	146
Carbonaceous material	5
Sandstone	48
Plastic sand	6
Sandstone	43

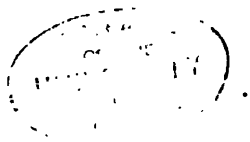
	Ft.
Coal (No. 4)	2.75
Sandstone	40
Shale clay	5
Coal (No. 5)	4
Carbonaceous material	7
Sandstone	31
Clay	8
Sandy shale	62
Coal (No. 6)	4
Sandstone	45

The shales found here are similar to those at Kummer and are suitable for sewer pipe and paving brick. The flint fire clay occurs in these deposits also. In addition to these, this company has at this place a light yellow, a white, a hard purple, and a light buff clay. These latter are used in the manufacture of dry press facing brick for building purposes.

Laboratory Examination.—The light yellow clay absorbs water rapidly and slakes quickly, breaking into a mass of thin flakes. This clay is very plastic and works nicely. The minimum tensile strength was 92 pounds to the square inch, the maximum was 249 pounds, while the average of the ten briquettes tested, however, was 185 pounds to the square inch. Only one of the briquettes tested showed a tensile strength of less than 131 pounds to the square inch. It required 27.5 per cent. of water to temper it to its most plastic condition, and it had an air shrinkage of 8.33 per cent. When burned at the fusing point of cone .01 (1,130 deg. C.) it vitrified and had a fire shrikage of 8.33 per cent. making a total shrinkage of 16.66 per cent. After having been burned at this temperature it had a dark red color, was steel hard, and had a clear metallic ring.

When viewed under the microscope, a few grains are seen that are as much as .1 of a mm. in diameter. There are many individuals that are about .05 of a mm. in diameter, but the larger part of the sample examined is made up of grains that are .02 of a mm. and less in diameter. Most of the larger grains are rounded to sub-angular in outline and more or less colored, usually a yellowish. Some of them are clear and transparent.

S. Shedd, Photo. BRICK PLANT OF THE ST. PAUL AND TACOMA LUMBER COMPANY, TACOMA



The minerals recognized were quartz, feldspar and particles of a black opaque mineral that is probably magnetite. When tested between the teeth very small particles of a distinctly gritty substance are noticeable.

The samples of this clay that were tested dried and burned without the least warping or cracking.

The hard purple clay which is found here, as its name would indicate, is a hard substance and has a slightly purple color. When pulverized it has but little plasticity and is not easily molded into various shapes. On account of its sandy nature it shrinks but little in drying and burning. It required 26 per cent. of water to bring it to its most plastic condition and shrank 3.45 per cent. in drying. When burned to the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 1.66 per cent., was purple in color and had become quite hard. It had not, however, vitrified at this temperature.

This clay does not slake on the addition of water. It has a low tensile strength, may be dried quickly without warping or cracking. The samples burned showed no signs of warping. When thoroughly mixed with water it has a yellowish color.

The light buff clay found here is hard, almost white in color, and rather coarse grained. Like the purple clay, it has very little plasticity and a very low tensile strength. The samples tested showed a minimum tensile strength of 20 pounds to the square inch, a maximum of only 32 pounds, while the average was only 24 pounds to the square inch. It required 27.5 per cent. of water to bring about its most plastic condition, it shrank 3.33 per cent. in drying, and when heated to the fusing point of cone .01 (1,130 deg. C.) had an additional shrinkage of 1.66 per cent.

After having been burned at this temperature this clay has a light buff color and is almost steel hard. On account of its sandy nature, it may be dried quickly without warping or cracking. It does not slake on the addition of water as most clays do. When pulverized and mixed with water it has a yellowish color.

The white clay mined at Taylor is not so hard as the buff or the purple. When water is added to this clay it slakes readily, breaking into a mass of thin flakes. This clay, like the others however, has but little plasticity and is not readily molded into various shapes. The sample tested showed a minimum tensile strength of 10 pounds, a maximum of only 13 pounds, while the average was 11 pounds to the square inch. It required 47 per cent. of water to temper it to its most plastic condition. It shrank 3.33 per cent. in drying and when heated to the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 1.67 per cent. After burning at this temperature it was almost pure white in color but was not very hard, as the grains had not cemented much. It dries and burns without warping or cracking.

There are many grains of sand in this clay which are as much as 1 mm. in diameter. Minute scales of white mica are also quite abundant. The following analyses show the chemical composition of these clays:

ANALYSES OF CLAYS FROM TAYLOR, KING COUNTY.

W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	62.42	68.98	72.27	74.77	72.30	41.36
Alumina (Al_2O_3)	17.98	15.56	16.16	16.06	19.95	40.49
Iron (Fe_2O_3)	4.34	4.90	1.56	0.70	0.71	0.71
Lime (CaO)	1.34	0.50	.....	.....	0.52	0.62
Magnesia (MgO)	1.84	0.36	0.29	0.56	trace	trace
Potash (K_2O)	2.78	2.30	2.90	2.34	2.98	1.47
Soda (Na_2O)	1.56	1.64	1.66	1.64		
Titanium (TiO_2)	0.68	0.84	0.68	0.50	.....	.....
Moisture (H_2O)	1.44	0.18	1.20	0.18	3.50	15.29
Loss on ignition	5.74	5.54	3.58	3.08		
Iron (FeO)	.....	.....	.....	.....	0.114	.....
Total	100.12	100.30	100.32	99.86	100.074	99.94
Total fluxes	12.54	10.04	7.21	5.74	4.424	2.80

I. Light yellow clay.

II. Hard purple clay.

III. Light buff clay.

IV. White clay.

V. and VI. Washington Geolog. Survey, Vol. I, p. 175. W. J. Rattle, analyst.

The above analyses show these clays to have a large amount of silica and numbers one and two especially have a considerable amount of fluxing substances. Numbers three and four should be quite refractory. In addition to the above described samples, one sample of the shale from this locality was also tested. This sample had a medium degree of plasticity, shrank 4.17 per cent. in drying, and when burned to the fusing point of cone .05 (1,050 deg. C.) had an additional shrinkage of 2.5 per cent. After having been burned at this temperature it was light red in color and about steel hard. It was completely fused at cone 10 (1,330 deg. C.) and had a dark gray color.

The following chemical analysis shows the composition of the shale from Taylor:

ANALYSIS OF SHALE FROM TAYLOR, KING COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	56.60
Alumina (Al_2O_3)	20.46
Iron (Fe_2O_3)	6.42
Lime (CaO)	1.30
Magnesia (MgO)	1.08
Potash (K_2O)	1.48
Soda (Na_2O)	0.66
Titanium (TiO_2)	0.47
Moisture (H_2O)	1.50
Loss on ignition	9.90
Total	99.82
Total fluxes	11.36

These shales were used for several years by the Denny Clay Company and vitrified paving brick were made from them. A comparison of the above analysis with those of Ohio and Missouri paving brick shales and clays given on page 23 of this report shows that the shale from Taylor has almost exactly the same composition as these. This shale is a little lower in total fluxes and hence a little more refractory. The physical properties of this shale are also very good and on the whole it would appear that it is well suited as a material from which to manufacture vitrified paving brick.

The following table is taken from Vol. I., Washington Geological Survey, page 177, and shows the results of tests of brick

made from the deposits worked by the Denny-Renton Clay and Coal Company:

REPORT OF MECHANICAL TESTS.

Made With the U. S. Testing Machine (Capacity 800,000 Pounds) at Watertown Arsenal, Mass., June 13, 1894. Material Contributed by the Denny Clay Co., at the World's Columbian Exposition, Chicago, Illinois.

DESCRIPTION.	Dimensions. Height	Dimensions. Compressed surface.		Sectional area	Weight dry.		Absorption of water. Total	By weight	By volume	First crack	Ultimate strength. Total	Per sq in.
	In	In.	In.	Sq. in.	Lbs	Oz.	Oz.	Per ct.	Per ct.	Lbs.	Lbs.	Lbs.
Facing Brick: Denny Clay Co	2.45	8 98	4 48	40 28	6	13¼	6¼	5.6	11.00	250,000	505,800	12,573
Facing Brick: Denny Clay Co	2.38	8 89	4.45	39.56	6	6¾	6	5.8	11.00	309,000	519,700	13,137
*Vitrified Pav'g Brick: Denny Clay Co	4.23	8 78	2.70	23 71	7	12¼	½	0.4	00 86	49,000	288,100	12,151
Vitrified Paving Brick: Denny Clay Co.	2.61	8.76	4.08	35.74	7	12¼	1	0.8	1 85	55,000	761,000	21,298

Description of the Plant.—There are two jaw crushers which are used in breaking the shales and two dry pans used for grinding them. The ground shale or the clay is thoroughly tempered in a long horizontal pug mill after which it is delivered to the brick machine. There is one auger stiff mud machine with an automatic wire cutting attachment with a capacity of 40,000 brick every ten hours.

The brick are all dried in a waste heat drier which has eight tunnels. There are eight large circular down draft kilns, each holding about 100,000 brick in which all the burning is done. The machinery is driven by a 250 horse power engine and four boilers.

The main products of this plant are high grade facing brick, which are made in a great many different colors by either using the different clays alone or in various combinations, fire brick, drain tile, hollow building blocks, fire proofing and electric conduit tile.

*Tested on edge.

AUBURN.

Auburn is about twenty miles south of Seattle on the Northern Pacific Railway and is the location of the Auburn pottery.

The clay that is used at this pottery is about ten miles east of Auburn on Green river in Section 27, T. 21 N., R. 63 E. It occurs at the base of a considerable bluff; where the deposit has been worked and opened up about nine feet in thickness of clay is shown. This varies considerably, in places being quite sandy, while in others it is practically free from sand. It also varies a great deal in color, in places being pure white, in others yellowish, while in still others it is blue. The clay is hauled by teams to Auburn and some of it has been shipped from there to Portland, Oregon.

Laboratory Examination.—The light gray clay has good plasticity and is easily molded into any desired shape. It had a minimum tensile strength of 58 pounds to the square inch, a maximum of 92 pounds, while the average of the briquettes tested was 70 pounds to the square inch. It required 24.5 per cent. of water to bring about its most plastic condition. It shrank 8.33 per cent. in drying and when heated to the fusing point of cone .010 (950 deg. C.) it showed no additional shrinkage. When heated to the fusing point of cone .01 (1,130 deg. C.) it had a fire shrinkage of 8.33 per cent. The sample of this clay tested dried without warping or cracking but in burning some cracks were developed. The color changed scarcely any in burning. It was completely vitrified at the fusing point of cone .01 (1,130 deg. C.). This clay is very fine grained, but contains some very fine gritty material.

The white clay from this place is less plastic than the one just described and has a less tensile strength. The sample tested showed a minimum of 26 pounds to the square inch, a maximum of 61 pounds, while the average of the briquettes tested was only 51 pounds to the square inch. It required 23.5 per cent. of water to bring it to its most plastic condition. It had an air shrinkage of 6.66 per cent. and when heated to the fusing point of cone .010 (950 deg. C.) it showed no additional shrinkage. After heating to the fusing point of cone .01

(1,130 deg. C.) it was vitrified and had shrunk 5 per cent. in burning. Its color after burning was almost white. This clay slakes very readily breaking into a mass of small, thin flakes. It has a considerable amount of very fine gritty material in it. The samples of this clay that were tested dried without cracking, but in burning some cracks were formed.

The sand which occurs here is mixed with the clay and used by this company in the manufacture of certain kinds of clay products.

The following analyses show the chemical composition of these two samples of clay and the sand:

ANALYSES OF CLAY AND SAND FROM EAST OF AUBURN, KING COUNTY.
W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	62.80	66.69	81.40
Alumina (Al_2O_3)	23.04	21.01	10.65
Iron (Fe_2O_3)	1.14	1.14	1.90
Lime (CaO)	0.40	0.38	0.50
Magnesia (MgO)	0.51	0.32	0.18
Alkalies (K_2O, Na_2O)	3.84	4.20	3.00
Moisture (H_2O)	1.65	0.62	0.20
Loss on ignition	6.58	5.87	2.42
Total	99.76	100.18	100.24
Total fluxes	5.89	5.99	5.58

I. Light gray clay. II. White clay. III. Sand.

The above analyses show these two samples of clay to have about the same composition as many of the best stoneware clays. The amount of fluxes is not high and the clay should resist fairly high temperatures. Some of its physical properties are not quite so favorable, however. For a good stoneware clay a tensile strength of at least 125 pounds per square inch is desirable.* These samples show a much lower tensile strength than this, the highest of all the samples tested being only 90 pounds to the square inch. The light gray especially is very fine grained and this is very desirable in a good stoneware clay.

Description of the Plant.—The Auburn Pottery works occupy a building 42 by 140 feet in dimensions and two stories

*Ries: Clays, Occurrence, Properties and Uses, p. 180.

high. One floor is used for a dry room and is steam heated. The plant is equipped with two jolly wheels, and two turning wheels for use in the manufacture of various kinds of stoneware. There is one circular down draft kiln twenty-two feet in diameter in which all of the ware is burned. There is a 40 horse power engine and a 50 horse power boiler. This boiler in addition to furnishing steam for the engine heats the dry room also.

Pierce County.

Pierce is the next county south of King and like it, extends from Puget sound on the west to the summit of the Cascade mountains on the east. The clay deposits of this county are very extensive and widely distributed and are either glacial, alluvial, or clay shales. The clay industry in this county, however, is not very extensively developed as yet.

The larger part of the county lies within the glacial area and the glacial clay is the most widely distributed of any of the clays. It is usually blue in color and very dense and compact. It is found mainly in what has been designated by Bailey Willis* as the Admiralty till. He says, however, that it may also occur in the Osceola till and that local deposits of this clay may be found in the Vashon drift. This glacial clay is of very widespread occurrence throughout the county and is very well adapted for making common building brick, sewer brick, and hollow ware of various kinds.

The Puget formation is quite common in parts of this county. In King county it is known to contain shales that are of economic value in the manufacture of clay products and in all probability they occur in Pierce county also. Alluvial clays occur along some of the larger streams but as a general thing these are not of a very good quality and at the present time are not being utilized.

The eastern part of the county is composed largely of rocks of a volcanic nature and these when they decompose, as a general thing at least, do not form high grade clays so that the

*Willis: U. S. G. S. Atlas, Fol. 5, Tacoma, Wash.

probability of finding these clays either as residual or as alluvial deposits along the streams in this county, is not very great. There is a possibility, however, that they may be found in connection with the Puget formation and that is where they should be looked for.

TACOMA.

Tacoma is the largest town in Pierce county and the second largest in western Washington and on account of its size it furnishes a good local demand for all classes of clay building material such as brick, terra cotta, etc. The rapid growth of the city has also furnished a very good market for sewer pipe and paving brick.

On account of this local demand certain branches of the clay industry have been developed in or near the city; the main branch of this industry, however, is the manufacture of ordinary building brick. The sewer pipe, paving brick, and terra cotta used here are all manufactured in other places and shipped to Tacoma.

St. Paul and Tacoma Lumber Company.—The brick yard operated by this company is located in the southeastern part of Tacoma. The clay used by the company is a surface deposit and is worked by a surface pit to a depth of about enght feet. The deposit appears to be of sedimentary origin as a part of it is stratified. The upper two feet of the deposit is dark, almost black, in color and contains a considerable amount of organic matter. Below this there are about three feet in which there are light and dark layers alternating with each other and below this as deep as the deposit is worked the clay is yellow in color.

The deposit is not entirely uniform throughout but is more sandy in some places than others. In actual work the different colored clays are all mixed and used in this way instead of each one being kept separate. A part of the clay is very plastic and sticky and in describing it the foreman spoke of it as a gumbo clay. The clay bank is situated about one half mile from the plant. The clay is loaded onto small cars and drawn by a horse over a tram to the plant.

S. Shedd, Photo. PLANT OF THE BELLINGHAM BRICK AND TILE COMPANY, ALGER

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Description of the Plant.—The clay on coming from the bank is passed through a pair of rolls and then goes to the pug mill where it is thoroughly mixed and tempered to the right consistency for making brick on a stiff mud machine. The company has one Brewer, No. 8, auger stiff mud machine which has a capacity of 40,000 brick a day. The number actually made in a day, however, is about 20,000. A part of the brick are dried on the yard in the open air and a part of them in a National five tunnel steam heated drier. The capacity of the tunnel drier is about 20,000 brick a day.

The brick are all burned in rectangular, up draft kilns, there being three of these in actual use.

Steam power is used to drive the machinery. There is a 40 horse power boiler and engine, the boiler furnishing the steam for heating the drier as well as for the engine.

This company makes between 4,000,000 and 5,000,000 brick a year. Nothing but the ordinary building brick are made here and these are all used in Tacoma.

Tacoma Trading Company.—This company operates a brick yard on Fox island which is a small island about six miles west of Tacoma. The company has its office and headquarters in Tacoma and furnishes brick for the local trade.

The clay bank being worked by this company is a very large one, the face of the workings showing an exposure of forty feet in depth and fifty feet horizontally.

The brick are manufactured by the stiff mud process, the plant being equipped with two brick machines having a capacity of 25,000 brick a day for one and the other has a capacity of 35,000 brick every ten hours. There is also two pair of rolls for pulverizing the clay and machinery for mixing and tempering it.

The brick are all dried in the open air by being spread out on the yard and burned in ordinary up draft scove kilns. There is a 50 horse power engine and boiler which furnishes the power for driving the machinery. The brick are loaded onto scows and towed to Tacoma where they are used. Common

building brick only are made by this company. About 4,000,000 brick a year are made at this yard.

LAGRANDE.

Lagrande is in the southern part of the county on the Nesqually river and is a station on the Tacoma Eastern Railroad. There is a deposit of clay at this place that is being worked by the Denny-Renton Clay and Coal Company. This clay is used in the terra cotta works at Van Asselt and is shipped by rail from Lagrande to that point.

The clay is light colored with a slightly yellowish color. It absorbs water and slakes very readily separating into a mass of small thin flakes. It has a fair degree of plasticity and is medium fine grained. It required 34 per cent. of water to bring about its most plastic condition, had a shrinkage in drying of 6.666 per cent. and when burned at the fusing point of cone .05 (1,050 deg. C.) it had an additional shrinkage of .833 per cent. It had not vitrified, however, at this temperature, was still soft, and almost white in color. It dried and burned without any signs of warping or cracking and had an average tensile strength of 75 pounds to the square inch.

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM LAGRANDE, PIERCE COUNTY.
W. R. BLOOR, Analyst.

Silica (SiO_2)	67.24
Alumina (Al_2O_3)	19.23
Iron (Fe_2O_3)	2.50
Lime (CaO)	0.34
Magnesia (MgO)	0.49
Potash (K_2O)	0.88
Soda (Na_2O)	....
Titanium (TiO_2)	0.25
Moisture (H_2O)	2.12
Loss on ignition	6.66
Total	99.79
Total fluxes	4.46

The total amount of fluxing substances in this clay, as shown by the above analysis, is small and on account of this it is not easily fused. The sample tested was heated to the fusing

point of cone 14 (1,410 deg. C.) and showed no signs of fusing. The composition of the clay is very similar to some of the best terra cotta clays in use in various parts of the United States.

Thurston County.

Thurston county is situated at the southern end of Puget sound and extends to the Nesqually river on the east, to Lewis county on the south and Chehalis county on the west. The county is, in the main at least, within the glacial area. The topography is mainly that of low hills and valleys with an occasional open prairie of small extent. In the extreme southeastern corner of the county it becomes rougher and is mountainous. The rocks throughout this county are mainly sedimentary and consist largely of sandstones and shales with glacial deposits of various kinds.

OLYMPIA

Olympia is the principal town in the county and is the seat of government of the state. It may be reached either by rail or by water and on account of the cheap water transportation on the Sound a large part of the clay building material used here is supplied by yards that are located outside of the county.

G. W. Hopp's Clay.—A sample of clay was received from Mr. Hopp of Olympia and tested in the laboratory. When dry, the clay is light gray in color, fine grained and free from gritty substances. It is hard, absorbs water and slakes very slowly. When wet it has a slightly greenish color and a fair degree of plasticity. It required 43 per cent. of water to temper it and give to it its greatest plasticity. In drying it had a shrinkage of 5 per cent. and after burning at the fusing point of cone .05 (1,050 deg. C.) it showed an additional shrinkage of 5 per cent. It was not, however, vitrified at this temperature, was light red in color, not hard enough for good brick, and would probably shrink a little more in complete burning. It fused at the melting point of cone 4 (1,210 deg. C.).

The following chemical analysis shows the composition of this clay:

ANALYSIS OF CLAY FROM OLYMPIA, THURSTON COUNTY.

W. R. BLOOR, Analyst.

Silica (SiO_2)	57.36
Alumina (Al_2O_3)	13.79
Iron (Fe_2O_3)	6.08
Lime (CaO)	3.89
Magnesia (MgO)	2.42
Potash (K_2O)	1.06
Soda (Na_2O)	0.10
Titanium (TiO_2)	0.50
Moisture (H_2O)	3.56
Loss on ignition	8.28
Total	99.91
Total fluxes	14.65

The above analysis shows that this clay is very similar in composition to the average clay used in the manufacture of ordinary building brick. (See page 33.) Neither does its composition differ very much from clays that are being used for vitrified paving brick. The amount of alumina, however, is a little low while the lime and magnesia are a trifle higher than the average. (See page 23.)

SNOHOMISH COUNTY.

This county is situated just north of King county and extends from Puget sound on the west to the summit of the Cascade mountains on the east. The whole of the county lies within the glaciated area and over the western part of it glacial material is very common. The glacial deposits consist mainly of sands, gravels, and till. Occurring in these in many places are deposits of clay of greater or less extent that are well suited for use in the manufacture of common building brick.

The eastern part of this county is in the Cascade mountains and hence very rough. During the time the glaciers covered a considerable part of western Washington, the ice probably covered the whole of this county. Glacial deposits are not of much importance, however, in this part of it. Throughout the eastern part of the county igneous rocks, such as granites, gneisses and rocks of this general type, predominate. These

rocks are such as, in general, form the better grades of clay when they decompose.

The conditions, however, in Snohomish county, in the main, are not very favorable for the accumulation of this decomposed material. The slopes are so steep in the mountainous part of the county that there is very little chance for the formation of residual clay deposits. Then the streams, in the main, flow very rapidly and are not depositing along their courses any but the coarser material such as sand and gravel.

At the present time so far as the writer has been able to learn there are no high grade clays known to occur in the county. The local demand for clay products of different kinds up to within the last few years has not been very great and the clays that are known to occur have not been extensively worked. This local demand is gradually increasing and more attention is being given not only to the development of the clay deposits that are already known but also to the finding of new and better grades of clay.

EVERETT

Everett is the largest town in Snohomish county and uses the larger part of the clay building materials manufactured in it. Clays suitable for the manufacture of common building brick are found in the immediate vicinity of the town, and brick yards have been established to supply the local demand.

Wassen Brick Yard.—This yard is situated in the southeastern part of the town. The clay that is being used at this yard varies considerably in the different parts of the bank. The deposit shows fairly well marked stratification especially in its lower part. This part is very fat plastic clay with a bluish color when wet and light gray when dry. The upper part of the bank is of a yellowish color, due probably to weathering and a change in the form of the iron. In places the deposit is quite sandy. The clay bank at this place is worked to a depth of about forty feet, the yellow and the blue clay being mixed together just as they come from the bank so that there is no expense for stripping or the removal of surface material. The clay

works fairly well. The brick crack somewhat, however, in drying and burning.

Description of the Plant.—The stiff mud process is used at this yard, the brick being made on an auger stiff mud machine which has a capacity of from 40,000 to 60,000 brick a day. The clay, when it comes from the bank goes through a disintegrator and then to a pug mill where it is thoroughly mixed and tempered before going to the brick machine. There is one hand power, wire cutting table in connection with the brick machine and one hand power repress machine which has a capacity of 8,000 brick a day.

A part of the brick is dried in steam heated tunnel driers and a part of them in the open air. The drier has four tunnels and a total capacity of about 26,000 brick a day and when more than this number is made they are spread out on the yard to dry. The brick are all burned in the ordinary up draft scove kiln, wood being used as fuel.

Steam power is used for driving the machinery, there being a 40 horse power engine and a 120 horse power boiler, which furnishes steam both for the engine and the drying tunnels.

The brick are of a good red color and appear to have good strength. About 6,000,000 brick a year are made at this yard, practically all of which are common building brick and are used in Everett.

Schaffer Brick Yard.—Mr. H. Schaffer operates a small brick yard in the northeast part of Everett. The clay that is used at this place is the ordinary bluish glacial clay that is so common throughout the Puget sound country and there appears to be a large body of it at this point.

The clay is pulverized by being passed through a pair of rolls and then thoroughly mixed and tempered. There is one brick machine with a short pug mill attached. This machine is the ordinary auger stiff mud machine and has a capacity of 25,000 brick a day. There is one hand power wire cutting table in connection with the brick machine. There is a dry house 50 by 80 feet, in which the brick may be spread out to dry, but most

of them, at present, are dried in the open air out in the yard. The brick are all burned in the up-draft scove kiln. This clay dries and burns without cracking or warping seriously and makes a very good looking common brick.

About 1,500,000 brick are made in a year at this yard.

Dregone Flower-Pot Plant.—A small flower-pot plant is being operated in the northern part of Everett by Mr. N. Dregone. The clay used at this place is a surface deposit which has a yellowish color and is probably a glacial clay that has changed from a blue to a yellow color on account of having been exposed to the atmospheric agencies and a change having taken place in the iron. The clay is very fat and plastic and works nicely. It burns to a good deep red color and makes a good appearing flower pot.

There is one flower-pot machine, which is operated by steam, on which the smaller sized pots are made. The larger sized flower pots are all molded in plaster of Paris molds. This is done on what is known as a potters' jolly wheel. This jolly wheel consists of a hollow receptacle in which the molds are placed, so arranged as to rotate horizontally. The interior of these molds have the shape of the exterior of the article to be molded. A lump of clay is placed in the mold and pressed into shape with the fingers, after which the operation is completed by means of an arm or pull-down which presses the clay firmly into the mold and gives the shape to the interior of the article.

The Dregone plant has one of these jolly wheels which is operated by steam. There is also one foot-power potters' wheel. The main building is 40 by 80 feet, two stories high, and is used very largely as a place in which to dry the flower pots. The clay is passed through a pair of rolls and pulverized, after which it is tempered in an old-fashioned wooden pug mill operated by a horse. There is a 10 horse power engine and boiler for operating the flower pot machine.

The flower pots are all burned in a permanent down draft rectangular kiln which is nine by nineteen feet and seven and one-half feet to the crown. The clay burns to a nice red color.

It is the intention of Mr. Dregone to enlarge the plant and make repress brick and drain tile.

Skagit County.

Skagit county is situated just north of Snohomish county and extends from Rosario strait on the west to the summit of the Cascade mountains on the east. Throughout the western part of the county are deposits of glacial material such as are found so widely distributed in western Washington. In the eastern part of the county through the Cascade mountains igneous and metamorphic rocks prevail. In some places in the western part sandstones, shales and slates of the Puget formation are known to outcrop.

Glacial clays are found in many places in the western part of the county, but on account of the fact that there are no very large towns in the county and hence no very great local demand for clay products, these have not been extensively developed. Alluvial clays are also found along some of the streams and at Baker, which is on the Skagit river about forty miles above its mouth, two cement plants have been installed to utilize a deposit of clay of this character which occurs there.

ALGER.

Alger is situated in the extreme northern part of Skagit county and is on a branch line of the Great Northern Railway. It is twelve miles south and a little east of the town of Bellingham.

Bellingham Brick and Tile Company.—The main office of this company is at Bellingham, but the plant and the clay bank are at Alger. This company has eighty acres of land at this place and a large body of clay. The clay in the upper part of the deposit is light yellow in color, while the lower part of the deposit has a blue color. A well has been drilled at the plant to a depth of one hundred feet and it is said that nothing but clay was encountered for the entire distance, The upper nine feet of yellow clay is probably the blue clay changed by weathering. The whole of the deposit is distinctly stratified, the layers being

S. Shedd, Photo. CLAY BANK OF THE HARPER BRICK AND TILE COMPANY AT HARPER

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practically horizontal. The individual layers in the main are very thin. The deposit is free from pebbles and gravel.

This clay occurs just a little south of Samish lake and the surface of the country between the southern end of the lake and where the clay is being worked at Alger is but a few feet above the lake. In all probability the lake, at one time, covered a much larger area than it does now and included all of the country around Alger. These clays consist of the material that has been finely pulverized by the glaciers that covered this part of Washington, and has been deposited in and filled up the lower part of the lake.

The deposit where it is being worked is not uniform in composition throughout its entire thickness, but is more sandy in some places than in others. A considerable part of the deposit is a fat, plastic clay, and a certain amount of sand or sandy clay mixed with it would improve it instead of injuring it. In the main, it works very smoothly and easily and dries rapidly without warping or cracking. It burns to a good red color and after burning it has a good metallic ring. The deposit is worked by a surface pit, the clay being loaded onto cars and drawn by means of a cable and steam hoist up an incline to the upper story of the mill.

Description of the Plant.—The stiff mud process is used entirely by this company. The clay is first passed through a pair of rolls to pulverize any lumps or small pebbles that it may contain, after which it goes to a long horizontal pug mill where it is thoroughly mixed and tempered. There is one auger stiff mud machine having a capacity of 40,000 brick a day, and also dies for making tile that may be attached to this same machine. The brick machine is supplied with an automatic wire cutting table. There is also one power repress machine which has a capacity of 20,000 brick a day.

The plant is supplied with a six tunnel steam heated drier. Each of these tunnels will hold fifteen cars of brick and the drier has a total capacity of 25,000 brick a day. When more than this is made, they are dried in the open air in the yard.

The brick are all burned in rectangular permanent walled, up draft kilns. The total capacity of the kilns is 1,500,000 brick. The main building which contains the clay working machinery is 40 by 90 feet with a shed 25 by 25 feet for the engine and boiler. This boiler also furnishes steam for heating the drier.

The brick made by this company are especially smooth and regular and are used very largely in Bellingham.

The following analysis of this clay is taken from a circular issued by this company and was made by W. H. Fuller:

ANALYSIS OF CLAY FROM ALGER, SKAGIT COUNTY.

Silica (SiO_2)	49.65
Alumina (Al_2O_3)	19.94
Iron (Fe_2O_3)	9.27
Lime (CaO)	2.58
Magnesia (MgO)	6.32
Alkalies (Na_2O, K_2O)	3.29
Moisture (H_2O)	2.15
Loss on ignition	5.85
Total	99.04
Total fluxes	21.45

According to the above analysis, the clay is very low in silica and high in fluxing substances. The iron and the magnesia is each especially high.

BAKER.

Baker is situated on the Baker river where it empties into the Skagit river, and a branch line of the Great Northern Railway, which extends from Burlington to Rockport, passes through it. The clays which occur here are found on either side of the Baker river. These deposits are very large, in each case extending along the river for a considerable distance and having great thickness. The different layers vary much in thickness and range from those that are only a few inches to those that are as much as three or four feet thick. The different layers vary also in composition, some of them being very fat and plastic, while others are quite sandy. This clay when dry is light gray and when wet is light blue in color.

This clay is being used by both the Washington Portland Cement Company and the Superior Portland Cement Company in the manufacture of Portland cement.

The following analyses show the chemical composition of the alluvial clay which occurs along Baker river at Baker:

ANALYSIS OF CLAY FROM BAKER, SKAGIT COUNTY.

CONSTITUENTS	I.	II.
Silica	58.75	55.90
Iron and aluminum oxides	25.94	25.50
Calcium carbonate	4.66	4.90
Magnesium carbonate	4.47	2.83
Sulphur	.....	.51
Alkalies	1.48	3.91
Combined water	4.60	6.45
Total	99.90	100.00

I. Analyzed by Prof. C. W. Johnson, Seattle, Wash.
II. Analyzed by F. C. Newton, Seattle.

Prof. Landes* has the following to say in regard to this clay deposit:

"The clay lies in horizontal beds in contact with limestone and represents silt brought down by Baker and Skagit rivers."

Other deposits are also found in this locality, some of them being up Jackman creek a few miles, while another very large one is located about two miles almost north of the town of Sauk. These deposits are very similar in appearance to the one at Baker, except that the deposit north of Sauk, so far as could be told, is practically free from sandy layers.

The following analysis of the clay from Baker was made by Mr. R. M. White, chemist at the Washington Portland Cement Works, and was furnished by the company:

ANALYSES OF CLAY FROM BAKER, SKAGIT COUNTY.

R. M. WHITE, Analyst.

Silica (SiO_2)	57.06
Alumina (Al_2O_3)	16.16
Iron (Fe_2O_3)	8.30
Calcium (CaO)	5.96
Magnesia (MgO)	3.20
Alkalies (K_2O, Na_2O)	2.22
Loss on ignition	6.22
Total	99.12
Total fluxes	19.68

*Cement Resources of Wash., Bull. U. S. G. S. 285, p. 380.

Whatcom County.

Whatcom county is situated in the northwestern part of Washington and extends from the Gulf of Georgia on the west to the summit of the Cascade mountains on the east. It is completely within the glacial area of western Washington and glacial deposits are very common over the western part of the county. These glacial deposits consist mainly of sands, gravel, and till, and in these in different places are found deposits of clay of greater or less extent, some of which are well suited as a material from which to manufacture certain kinds of clay products.

The eastern part of the county is very rough and mountainous and the rocks are very largely igneous and metamorphic and consist of granites, gneisses, schists, and slates. In the western part of the county beneath the glacial deposits the rocks are sedimentary and consist of sandstones, shales and slates, and belong, in part at least, to the Puget formation.

There are a number of good-sized streams which rise in the Cascade mountains and flow across the county, but very few deposits of alluvial clay are found along them. The shales and slates which occur in the Puget formations, and which are being utilized in some parts of Washington, may also be found of value in Whatcom county. At present, however, they are not being utilized.

There is a fairly good local demand at the present time (1909) for the different kinds of brick for building purposes as well as for sidewalks and street paving. Common building brick, however, are all that are made in the county at present.

BELLINGHAM.

Bellingham is the principal city not only in the county, but also in the northwestern part of Washington. It is in the western part of the county on Bellingham bay, and is on the lines of the Great Northern and the Northern Pacific railways. It furnishes almost the whole of the local demand for clay building material, and on account of this, some of the clays in or near the town are being utilized.

J. F. Miller and Brothers' Brick Yard.—The Miller Brothers operate two brick yards at Bellingham. One of these is located on Ellis street near Gladstone, while the other is at the corner of Monroe and Potter streets. The clay is practically the same in each of these yards.

The deposit at these places is very extensive and appears to be of good quality. The upper nine feet of the deposit is entirely different in appearance from the lower part of it. The upper part is all that has been used so far, but it is the intention to soon begin using the lower part of the bed. The upper part of the deposit is a fat plastic clay and has the appearance of being a weathered glacial clay.

Below this upper clay is a layer a foot or so in thickness that is more or less sandy and below this is a dark blue colored clay. Borings have been made in this to a depth of thirty-five feet and the clay is found to be very uniform for the entire distance. This is a very fine grained glacial clay which, at this place, appears to be practically free from all foreign substances such as gravel and pebbles. It is claimed by Mr. Miller that this is a good pottery clay. From its appearance, however, it is the opinion of the writer that in all probability it will be found on analysis that it contains a high percentage of fluxing substances. This is true in general of these glacial clays in western Washington, and this makes them poorly suited as a material from which to manufacture stoneware. In some cases, however, clays which do contain a large amount of fluxing material may be used for stoneware provided they have the required physical properties, and this clay does appear to have these.

The clay works fairly well and dries and burns with very little warping and cracking.

Description of the Plant.—The yard at the corner of Monroe and Potter streets is supplied with one Potts soft mud brick machine which has a capacity of 30,000 brick a day. There is also one hand power repress machine which has a capacity of

5,000 brick each day. At this yard the brick are all dried in the open air by being spread out on the yard and are burned in the ordinary scove kiln. The power is furnished by a 40 horse power engine and boiler. The yard on Ellis street near Gladstone is equipped with one Ames Special stiff mud brick machine with a capacity of 25,000 brick a day and one Morton soft mud machine with a capacity of 30,000 brick a day. There is also one hand power repress machine with a capacity of 5,000 brick a day which is used in repressing some of the soft mud brick. This plant is also supplied with machinery for pulverizing and tempering the clay, and a hand power wire cutting table for use in connection with the stiff mud machine. There is a steam heated tunnel drier at this yard with a capacity of 25,000 brick a day. A considerable part of the brick made here are spread out on the yard and dried in the open air. They are all burned in up draft scove kilns. An 80 horse power engine and boiler furnish the power for this plant.

SUMAS.

Sumas is in the extreme northern part of Whatcom county and may be reached by either the Northern Pacific or the Bellingham Bay and British Columbia Railroad. Large deposits of clay are said to occur near the town, and the Sumas Fire Brick Company has been organized for the purpose of working these deposits. The writer, however, has made no examination of these deposits, the information given him having all been furnished by Mr. Tom Brown, secretary of the company.

Sumas Fire Brick Company.—This company has two hundred acres of clay land situated on the Bellingham Bay and British Columbia Railroad two and one-half miles southeast of Sumas. Several grades of clay are said to occur on the property and the following section has been worked out by Mr. J. B. Umpleby:

SECTION SHOWING THE DEPOSITS ON THE PROPERTY OF THE SUMAS FIRE BRICK COMPANY.

	Feet.	Inches.
Clay, dark brown on exposure; concretions make up the entire member	10	4
Beds concealed	57	...
Sandstone on top, grading downward into conglomerate	8	4
Coarse sandstone containing pebbles	15	...
Clay, buff in color	4	1
Clay, arenaceous, finer near top	7	6
Sandstone containing pebbles, some very coarse	20	...
Clay, increasing in sand toward base. Clay is very compact and every physical character points to a good quality	7	6
Sandstone, very argillaceous at top and grading downward into fine sandstone	9	6
Beds concealed	180	...
Clay, grading downward into sandstone, entire member is iron stained and accretionary in form	29	8
Clay, firm, light colored, constant in texture from hanging to foot wall	18	...
Sandstone, coarse, very poorly cemented, contains large gravels, and grades into conglomerate at base	55	...
Clay, light buff, slightly iron stained	3	5
Sandstone	1	...
Clay, stratified, buff color, medium grade	18	5
Sandstone	1	...
Beds largely concealed; small exposures show it to be largely a clay member	16	...
Beds largely concealed; an exposure of very good clay near base	7	...
Beds concealed; nature of topography would indicate a clay formation	114	...
Clay, found about mid-way in the above layer and is seemingly a very good clay	6	8
Clay, grading downward into an argillaceous sandstone	4	6
Sandstone, clay at base	10	8
Clay, maroon, constant in texture	13	6
Sandstone, coarse gray	8	...
Sandstone, very argillaceous and slightly conglomeratic	15	11
Conglomerate cemented by clay; contains principally quartz pebbles with a low percentage of basic pebbles intermixed.	12	...
Clay, light, firm, compact, and pure; apparently a very good clay; lower-limit and hence thickness unknown; as exposed	2	...
Beds concealed	15	...
Conglomerate, cemented by clay	6	4
Clay, slightly sandy, very compact, iron stained	2	...

Samples of the clay from these deposits were received from Mr. Brown, but no tests have been made on them as yet. In an unpublished report, Mr. Umpleby gives the following as regards these deposits. These members have a westerly dip, varying from 25 degrees on the east, to 39 degrees on the west, and are interstratified with the country rock.

The following analyses show the chemical composition of these clays:

ANALYSES OF CLAY FROM SUMAS, WHATCOM COUNTY.

CONSTITUENTS	I.	II.	III.
Silica (SiO_2)	48.7	69.21	47.84
Alumina (Al_2O_3)	22.1	12.37	35.14
Iron (Fe_2O_3)	4.9	2.11	
Lime (CaO)	0.9	0.57	1.23
Magnesia (MgO)	0.3	0.54	0.29
Alkalies (K_2O, Na_2O)	trace	2.06	.....
Water (H_2O)	14.0	5.98	15.90
Volatile matter	.....	6.74	.....
Total	100.9	99.60	100.37

I. and II. analyzed by H. K. Benson, Dept. of Chem., University of Washington.
III. analyzed by Arthur G. Smith, general manager Washington Portland Cement Company, Baker, Washington.

The above analyses show a small amount of fluxing substances in each sample and each one judged by its composition alone would probably require a fairly high temperature to fuse it. The amount of silica in No. I. and No. III. is low, while the per cent. of alumina is high. The clay from this locality varies in color, some samples being light gray, others yellowish, while still others are light blue. Some of the samples have a fair degree of plasticity, while in others it is almost entirely absent. They are all rather hard, absorb water and slake, some of them rapidly and others very slowly.

KENDALL.

This is a small place in the northern part of the county on the line of the Bellingham Bay and British Columbia Railroad. In this locality large deposits of glacial clays are reported by Prof. Henry Landes* of the State University at Seattle.

The following partial analyses are given by him:

CONSTITUENTS	I.	II.
Silica	61.27	57.06
Iron and aluminum oxides	25.20	26.50
Calcium carbonate	2.96	10.62
Magnesium carbonate	4.68	1.13
Alkalies	.....	2.55

I. Analyzed by D. N. Riedle, Montavilla, Oregon.
II. Analyzed by A. H. Cederberg.

*Cement Resources of Wash., Bull. U. S. G. S. 285, p. 379.

S. Shedd, Photo. PLANT OF THE HARPER BRICK AND TILE COMPANY, HARPER

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San Juan County.

San Juan county is situated in the northwestern part of the state and includes a number of distinct islands. Most of the towns in the county are so small that the local demand for building material manufactured from clay is not very large. Good clays, however, are found in some places in the county and have been used for the manufacture of common brick.

ORCAS ISLAND.

On the northwest shore of Orcas island a body of very plastic clay occurs from which brick have been made. This clay is light gray in color and fine grained. It covers a large area and has a depth of from twenty-five to thirty feet.

The following analyses show the chemical composition of the Orcas island clays:*

Analyses of Clay and Shale from Orcas Island, San Juan County.. A. H. Cederberg, Analyst.

CONSTITUENTS	I.	II.	III.	IV.
Silica	62.8	39.80	57.8	58.2
Iron and aluminum oxides	19.2	21.62	21.4	23.9
Calcium carbonate	10.2	29.10	5.1	6.3
Magnesium carbonate	.9	2.91	3.1	4.1
Sulphur	.....	.41	.5	.8
Alkalies, etc.	undet.	2.15	2.1	2.9

I. and II. Shale.
III. and IV. Clay.
*Bull. U. S. Geological Survey, No. 285, p. 378.

SAN JUAN ISLAND.

At Roche Harbor large deposits of clay are said to occur, some of the deposits having a thickness of as much as forty feet.

The following analyses show the chemical composition of this clay*:

Analyses of Clay from Roche Harbor, San Juan County.

CONSTITUENTS	I.	II.
Silica	55.81	56.35
Iron and aluminum oxides	26.28	24.62
Calcium carbonate	4.34	3.66
Magnesium carbonate	3.39	2.58
Sulphur	trace	.31
Alkalies	3.98	3.94
Moisture	6.11	7.52
Total	99.91	98.98

I. Analyst not given.
II. F. C. Newton, Seattle, Wash., analyst.

*Bull. U. S. Geological Survey, No. 285, p. 378.

LOPEZ ISLAND.

On the northern end of Lopez island three and one half miles from the town of Lopez is a large body of clay. The deposit is thirty feet thick and very uniform in composition, but few sandy layers occurring in it. When wet, this clay is light blue in color, and when dry, is light gray. It absorbs water and slakes quickly, breaking into a mass of very small particles. It has a fair degree of plasticity and should work easily. This clay is not being used at the present time, (Sept. 1909,) but it is well suited as a material from which to manufacture common building brick or drain tile.

The following analysis shows the chemical composition of this clay:

ANALYSES OF CLAY FROM LOPEZ ISLAND, SAN JUAN COUNTY.

A. A. HAMMER, Analyst.

Silica (SiO_2)	59.40
Alumina (Al_2O_3)	19.58
Iron (Fe_2O_3)	6.44
Lime (CaO)	4.26
Magnesia (MgO)	4.13
Potash (K_2O)	0.75
Soda (Na_2O)	0.41
Loss on ignition	4.38
Total	99.35
Total fluxes	15.99

The amount of the fluxing substances in this clay is great enough to make it fuse at low temperatures.

KITSAP COUNTY.

Kitsap county is situated just west of King county, and is bounded on the east by Puget sound, on the south by Pierce and Mason counties, and on the west and north by Hood canal. The whole of the county is low, in no case being more than about one hundred feet above sea level. It lies entirely within the glacial area of western Washington and on account of this fact the surface material over practically the whole of the county is made up of glacial deposits of sand, gravel, and till.

HARPER.

Harper is located on Puget sound in the eastern part of the county and is about twelve miles southwest of Seattle. At this

point a large body of clay occurs and is being utilized in the manufacture of common brick.

Harper Brick and Tile Company.—The main office and headquarters of this company is in Seattle but its clay bank and plant for the manufacture of brick and tile are at Harper and are in Sec. 2, T. 23 N., R. 2 E.

The clay at this point is the ordinary glacial clay. It occurs in a distinctly stratified deposit the layers of which are usually thin and practically horizontal. The point where the bank has been opened is about eighty rods west of the plant. At this place the workings have exposed a thickness of about forty feet of clay and the bottom of the deposit is not yet exposed. In a small stream about twenty feet below the workings this same clay is exposed proving a thickness of at least sixty feet.

The whole deposit is covered with a thin layer of oxidized clay which contains more or less organic matter. This deposit is not entirely uniform there being some layers that contain a considerable amount of sand. A large part of the deposit, however, is a very fat plastic clay so that some sand is a benefit rather than an injury to it. In actual practice the different layers are mixed and the whole of the deposit used.

Some prospecting has been done over this property by digging pits at various places and the extent of this clay has been proven to be very great.

Laboratory Examination.—This clay when dry is of a light grayish color, is very fine grained and free from any gritty particles, is very plastic and works nicely, and requires 36 per cent. of water to temper it and bring about its most plastic condition. The maximum tensile strength was 135 pounds to the square inch, the minimum was 90 pounds, while the average was 110 pounds to the square inch. It dried and burned without warping or cracking, had an air shrinkage of 6.67 per cent. and when burned at the fusing point of cone .010 (950 deg. C.) it had an additional shrinkage of 1.67 per cent., making a total shrinkage of 8.34 per cent. After having been burned at the fusing point of cone .05 (1,050 deg. C.) it showed no additional shrinkage,

was not vitrified, nor very hard. It completely fused at cone 4 (1,210 deg. C.) and had a dark brown color.

Description of the Plant.—The clay working plant of this company is situated on the water's edge so that the brick may be readily loaded onto scows for shipping. The clay is brought to the plant from the bank on tram cars drawn by a horse.

There is one pair of conical rolls for pulverizing the clay, one long horizontal pug mill for mixing and tempering it, and one upright auger stiff mud brick machine. The brick machine has a capacity of 40,000 a day and is supplied with an automatic, side wire cutting table. There is one repress machine for facing brick but this is not being used at the present time. (July, 1906.)

The brick are all dried in a long eight tunnel drier which is heated by what is known as the waste heat system. This consists in taking the waste heat from the burning kilns and forcing it through the drying tunnels. The heat is caused to circulate through these tunnels by means of a rotary circular fan. All of the brick are burned in down draft permanent kilns. There are two of these kilns, each having six chambers. In these kilns the walls separating the different chambers are permanent. Each chamber has a capacity of about 46,000 brick. The brick are burned in from six to nine days. They have a good color, a good degree of hardness, and are very smooth and regular in outline. Nothing but common building brick are made here.

The brick are all loaded onto scows and taken to various points around Puget sound. This gives very cheap transportation and allows the company to compete in practically all of the cities around the Sound.

PORT ORCHARD.

Port Orchard is situated on the southeast shore of Port Orchard bay and is twelve miles south of Seattle. Glacial clays are found around here and have been used for the manufacture of common building brick.

Port Orchard Brick Yard.—This clay working plant is located near the water's edge about one and one-half miles west of Port Orchard. The clay used here is about one hundred fifty feet from the plant and is in Sec. 34, T. 24 N., R. 1 E. The clay bank is above the plant so that there is about 15 feet difference in elevation between the bottom of the clay pit and the upper floor of the building. The clay is the blue glacial clay. It is plainly stratified, and lies almost horizontal. On the surface is a layer about three feet thick of decomposed and weathered clay material. Below this is twelve feet of a fat, plastic blue clay and then comes about four feet of a more sandy, bluish material. Below the sandy material is more blue clay.

The deposit is worked by an open cut, the clay loaded onto cars which run by gravity over a short tram, that connects the clay pit with the plant, the loaded cars pulling the empty ones up to the pit.

Description of the Plant.—The plant located here is equipped with a pair of rolls for pulverizing the clay, a pug mill for mixing and tempering it, one auger stiff mud machine with a capacity of 50,000 to 75,000 brick a day, and one automatic wire cutting table. At the time this yard was visited about 25,000 brick were being made each day. They were being dried in the open air and burned in up draft rectangular kilns. Power is furnished by a 30 horse power engine and a 50 horse power boiler.

Nothing but common building brick are made at this yard and these are all loaded onto scows and sent to the different towns around Puget sound.

Lewis County.

Lewis county is situated well toward the southern part of the state and extends from the foothills of the Coast mountains on the west to the summit of the Cascades on the east. The western half of the county lies within the Puget sound basin or the low depression between the Coast mountains and the Cascade mountains. Throughout this part of the county the prevailing rocks are sandstones, shales and slates, which are of the Eocene age.

These deposits, especially the sandstones, contain well preserved marine fossils. Clays are very common in this part of the state and they have been developed and are being used in a few places in the manufacture of brick, drain tile, and sewer pipe.

SOPENAH.

Sopenah is situated in the Cowlitz valley in the extreme southern part of Lewis county on the main line of the Northern Pacific Railway. Large deposits of clay occur around this place and a considerable clay industry has been developed.

Little Falls Fire Clay Company.—This company has its plant located here and uses the clay that occurs a little east of the town. These clays have been formed by the decomposition of the grayish drab colored shale which occurs in this locality. The clay varies much in color, in some cases being yellow, in others deep red, while in still others it is almost white. The texture varies from fine to quite coarse. In places there is more or less gravel mixed with the clay and when this is considerably decomposed as it is in many cases, it is crushed and mixed with the clay and is said to be very beneficial in its effects.

These deposits have been worked at a number of places in this vicinity by open cuts, and the clay hauled on tram cars to the plant. In some places the clay is covered with a thin layer of gravel which has to be removed, while in the others the surface material is of such a nature that it is mixed with the clay and used.

Laboratory Examination.—Two samples of this clay were tested and analyzed, one being light gray in color, while the other was light yellow.

The light gray sample is fine grained and slakes readily. It required 36 per cent. of water to bring about its most plastic condition. It had a shrinkage in drying of 8.33 per cent. and when heated to the fusing point of cone .010 (950 deg. C.) it showed an additional shrinkage of 4 per cent. After having been heated to this temperature it was light red in color and still soft. After heating to the fusing point of cone .01 (1,130 deg. C.) it showed a total fire shrinkage of 11.66 per cent., was light gray in color, and extremely hard.

It dried without cracking, but in burning at high temperatures some cracks were formed. This clay showed a minimum strength of 69 pounds to the square inch, a maximum of 84 pounds, while the average was 79 pounds to the square inch. It had a fair degree of plasticity.

A sample of this clay was tested by Prof. Edward Orton, Jr., Columbus, Ohio, and found to completely fuse at the melting point of cone 20, or about 1,530 deg. C.

The sample of the yellow clay was more plastic than the other and had a higher tensile strength. The minimum of the samples tested was 120 pounds to the square inch, the maximum 194 pounds, while the average of the eight briquettes tested was 157 pounds to the square inch. It required 26 per cent. of water to temper it to its most plastic condition.

It dried without warping or cracking and shrank 9.33 per cent. When heated to the fusing point of cone .010(950 deg. C.) it had an additional shrinkage of 1.67 per cent. and was a good brick red in color. It had not vitrified, however, at this temperature. When heated to the fusing point of cone .01 (1,130 deg. C.) it had a total fire shrinkage of 7.4 per cent. It vitrified at this temperature and was dark red in color. In practice these clays are mixed and burned to the fusing point of cone 4 (1,210 deg. C.).

The following analyses show the chemical composition of these samples:

ANALYSES OF CLAY FROM SOPENAH, LEWIS COUNTY.

W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.
Silica (SiO_2)	55.82	59.86
Alumina (Al_2O_3)	19.43	19.43
Iron (Fe_2O_3)	2.88	5.15
Lime (CaO)	1.13	1.40
Magnesia (MgO)	0.46	1.70
Potash (K_2O)	0.80	0.38
Soda (Na_2O)	0.95	0.32
Titanium (TiO_2)	1.15	1.15
Moisture (H_2O)	7.72	2.78
Loss on ignition	7.82	6.48
Manganese (MnO)	2.04	0.61
Total	100.00	99.26
Total fluxes	8.91	10.71

I. Light yellow clay.
II. Dark yellow clay.

The above analyses show these samples to be low in the amount of total fluxing substances. Number II. has enough iron, however, so that it burns to a deep red color.

Description of the Plant.—The clay is ground in a dry pan and then thoroughly mixed and tempered in a pug mill if it is to be used for sewer pipe or paving brick. There is one paving brick machine having a capacity of 40,000 brick a day and one dry press machine having a capacity of 18,000 brick every ten hours. For the manufacture of sewer pipe the company has one sewer pipe machine on which pipes of various sizes up to twenty-four inches in diameter may be made. The main building is 80 feet wide, 240 feet long, and three stories high. This building is steam heated and a large part of it is used as a place in which to dry the sewer pipe. There are seven large circular down draft kilns in which all of the material is burned.

The machinery is all operated by steam power, there being a large engine and boiler for this purpose. Coal is the main fuel used in burning the different wares.

This company manufactures sewer pipe, paving brick, drain tile, and dry press facing brick. The company also makes the fire brick, that it uses, from a white clay found here.

CHEHALIS.

Chehalis is situated in the northern part of the county and is on the main line of the Northern Pacific Railway between Tacoma and Portland. It furnishes a considerable demand for common building brick and a yard is operated here to supply the local demand. The clay occurs in low hills just north of town. It is dark colored at the surface but is a yellow color a short distance below the surface.

Chehalis Brick and Tile Company.—Two samples of the clay used by this company have been tested and analyzed, one a dark colored clay while the other was yellowish in color. The dark colored one required 27 per cent. of water to temper it, shrank 6.66 per cent. in drying, and when burned to the fusing point of cone .010 (950 deg. C.) it was light colored, still soft, and showed no additional shrinkage. When heated to the fusing

S. Shedd, Photo. SEWER PIPE PLANT OF THE LITTLE FALLS FIRE CLAY COMPANY, SOPENAH

point of cone .01 (1,130 deg. C.) it had softened enough so that it would not retain its shape and was dark chocolate brown in color. The samples tested showed a maximum tensile strength of 133 pounds to the square inch, a minimum of 102 pounds, while the average of the ten briquettes tested was 108 pounds to the square inch. This clay has a fair degree of plasticity. Physical tests were not made on the yellow clay from here, but its physical properties are probably very similar to the above.

The following chemical analyses show the composition of each of these clays:

ANALYSES OF CLAY FROM CHEHALIS, LEWIS COUNTY.
W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.
Silica (SiO_2)	58.75	72.50
Alumina (Al_2O_3)	18.27	13.05
Iron (Fe_2O_3)	3.86	4.58
Lime (CaO)	0.86	0.60
Magnesia (MgO)	1.68	0.70
Potash (K_2O)	2.18	1.84
Soda (Na_2O)	1.58	0.89
Titanium (TiO_2)	0.85	0.42
Manganese (MnO)	1.20	.....
Moisture (H_2O)	2.12	2.00
Loss on ignition	8.66	4.24
Total	99.96	100.77
Total fluxes	12.16	8.98

I. Dark colored clay.
II. Yellow clay.

The above analyses show nothing very peculiar as regards this clay. It is about an average clay, as far as composition is concerned, for the manufacture of common brick and drain tile. (See page 33.)

Description of Plant.—The yard is supplied with one auger stiff mud brick and tile machine, one crusher and a pug mill for tempering the clay. There is a small steam dry house in which the brick are dried and they are all burned in scove kilns. Steam is used for driving the machinery. About 1,000,000 brick are made each year.

CENTRALIA.

Centralia is about four miles north of Chehalis on the main line of the Northern Pacific Railway and at the confluence of the Chehalis and Skookumchuck rivers. It is a town of considerable size and furnishes a fair local demand for ordinary building brick.

Wingard Bros. Brick Yard.—A small yard is being operated at this place by Wingard Bros. The yard is situated on the bank of the Chehalis river and the clay is simply a surface deposit that has been formed by the stream. Two samples of this clay were tested and analyzed, one being a light yellow and the other a darker yellow in color.

The dark yellow clay is fine grained and has good plasticity. It required 30 per cent. of water to temper it, shrank 8.33 per cent. in drying, and when burned at the fusing point of cone .01 (1,130 deg. C.) it had an additional shrinkage of 1.66 per cent. After burning at this temperature it was dark red in color and about six in hardness. It fused at the melting point of cone 8 (1,290 deg. C.) and was a very dark, almost black color. The maximum tensile strength was 80 pounds to the square inch, the minimum 44 pounds, and the average of the five briquettes tested was 65 pounds to the square inch. This clay would require very careful drying and burning to prevent warping and cracking.

The light yellow clay has good plasticity and is fine grained. It required 34 per cent. of water to bring about its most plastic condition, had a shrinkage of 11.66 per cent., and when heated to the fusing point of cone .01 (1,130 deg. C.) it shrank 3.33 per cent. additional. After having been burned at this temperature it was almost steel hard and was dark red in color. It was not fused at the melting point of cone 12 (1,370 deg. C.). It had a very low tensile strength, the maximum of the briquettes tested being only 15 pounds to the square inch, while the minimum was nine pounds. It cracked and warped more or less both in drying and burning.

The following chemical analyses show the composition of these samples:

ANALYSES OF CLAYS FROM CENTRALIA, CHEHALIS COUNTY.
W. R. BLOOR, Analyst.

CONSTITUENTS	I.	II.
Silica (SiO_2)	60.10	54.88
Alumina (Al_2O_3)	16.61	21.25
Iron (Fe_2O_3)	8.55	7.00
Lime (CaO)	1.43	0.80
Magnesia (MgO)	1.29	1.04
Potash (K_2O)	1.18	0.36
Soda (Na_2O)	0.80	0.69
Titanium (TiO_2)	0.98	1.06
Moisture (H_2O)	3.04	5.30
Loss on ignition	6.60	7.62
Total	100.58	99.95
Total Fluxes	14.23	10.95

I. Light yellow clay.
II. Dark yellow clay.

The above analyses show a slight difference in composition in the two samples. They are about the average in composition, however, of clays that are used in the manufacture of common building brick and drain tile. (See page 33.)

Description of the Plant.—The plant is only a small one, having one auger stiff mud machine with a capacity of 20,000 brick a day, one pug mill for tempering the clay and two small circular down draft kilns in which the brick and tile are burned. The brick are all dried in the open air. Common building brick and drain tile are made here.

CLARKE COUNTY.

Clarke county is situated in the southern and western part of the state. It is bounded on the south and west by the Columbia river, and the eastern part of the county is in the low foot hills of the Cascade mountains.

VANCOUVER.

Vancouver is the principal town in the county and furnishes the largest local demand, of any town in it, for clay building material. Five miles above Vancouver, on the Columbia river,

large clay deposits occur and a considerable brick industry has been established, the brick being used in Vancouver and Portland, Oregon.

According to Mr. N. H. Darton* of the U. S. Geological Survey, twenty feet of gray brick loam are found above six feet of a finer blue clay. The blue clay is designated by him as terra cotta clay and has been mixed with shale brought from some of the coal mines in Washington and used for making terra cotta.

*Bulletin U. S. Geological Survey, No. 387, p. 18.

CHAPTER XIV.

FUTURE DEVELOPMENT OF THE CLAY INDUSTRY OF WASHINGTON.

Brick and stone have been used to a greater or less extent in the construction of public buildings and business blocks in Washington for many years past, but only in a very few places have they been used in the construction of residences. Washington is well supplied with the best of timber from which to manufacture lumber and this has been cheaper and on account of this it has been the almost universal custom to construct houses out of lumber. In eastern Washington, however, timber has been scarce and there has been a greater tendency toward the use of other kinds of building material. Even here, however, the principal material used for dwellings has been lumber.

While it is true that Washington has large quantities of timber suited to the manufacture of high grade lumber at the same time the price of lumber has increased very materially within the last few years and as it becomes scarcer the price will go still higher until eventually it will be more expensive than brick or terra cotta. Constant improvements are being made in the various kinds of clay working machinery and in the methods of manufacture of different kinds of clay wares and these are tending to cheapen clay building material.

Washington is well supplied with clays suitable for the manufacture of all kinds of building brick. Clay that will make a common building brick is widely distributed throughout the state and in fact there are but few, if any, localities where such clay does not occur. There are several places also where clays that are especially well adapted to the manufacture of the best grades of ornamental brick are found, and this phase of the clay industry should be very much better developed in the near future than it is at the present time.

Drain tile have been used but little in Washington up to the present time but their use is gradually increasing and eventually

in certain parts of the state they should be extensively used. Clays from which drain tiles may be made are found in many parts of Washington and this should in time, become one of the important phases of the clay industry of this state.

Paving brick and sewer pipe are used quite extensively in some parts of Washington, even at the present time, but as the cities within the state become larger the demand should become much greater.

In only a few places within the state are sewer pipe being manufactured and in but one place are paving brick produced. What has been designated as the Puget formation covers a large area in Washington and this contains immense quantities of shales and in places these are known to be well adapted to the manufacture of paving brick and it is very probable that a careful examination of these shales would show many places where good paving brick might be made from them. Large quantities of sewer pipe and paving brick should be used in Washington in the next twenty years and these should all be manufactured within the state, and from home material. The shales which occur in connection with the coal deposits of the Puget formation are perhaps the most promising material found within the state from which to manufacture vitrified paving brick. The Puget formation is also the source of good sewer pipe material but in a number of places good material, for the manufacture of this class of clay goods, is found, which does not belong to this formation.

Many of the clays within the state are suitable for the manufacture of dry press brick and are being used for these at present. In places various colored clays are found, and by mixing these in various proportions bricks of different colors may be produced. Good terra cotta clays are found in several places in Washington. The demand, however, until very recently has not been very great, and on account of this the terra cotta industry has not reached any very great development. Within the last few years the demand has increased and this has caused a considerable increased development of this phase of the clay industry.

Clays are found within the state that are well suited to the manufacture of common stoneware. These occur in a number of different places and are being used somewhat at present. There is a chance, however, to very greatly increase the amount manufactured of this kind of material. Slip clays are known to occur at one or two places in the state and these may prove of value to the stoneware and terra cotta industries.

Fire clays of good quality are known to occur in several places and as the demand for materials to resist high temperatures gradually increases this phase of the clay industry will be better developed. The clay that resists the highest temperatures, thus far found in Washington, is the flint fire clay found in the coal measures of the western part of the state. This, however, has scarcely any plasticity and does not make a very firm solid brick. On account of this a highly plastic clay is needed to mix with it to make it bond, and for such a clay careful search should be made.

In 1908 the value of the products of the clay working industries of Washington was $2,104,298, and while the state was thirteenth in rank in the production of clay wares it produced only 1.58 per cent. of the total value of the output of the United States.* This amount should be very materially increased in the very near future.

There are vast opportunities in Washington for an increased development of the clay industry. This is true of no one phase of the industry alone, but is true of almost all of them. Building operations and improvements of various kinds are being carried on very extensively in almost all of the towns and cities throughout Washington and there is no good reason why the clays found in various parts of the state should not be converted into the different kinds of products to be used in these improvements. It seems safe therefore, to venture the statement that the outlook for the clay industry in Washington is very bright, and that there will be a steady increase in the annual production of the various kinds of clay wares.

*Mineral Resources of the U. S. Geological Survey, Washington, D. C.

Plates XXXVIII to XLII, inclusive, show the results of fusion tests on some of the Washington clays. These clay cones were of the same size and shape as the test cones and were placed in the furnace in such a position that they would be under the same conditions as the test cones. As the cone begins to fuse it commences to bend and it is considered completely fused when the point just touches the bottom of the furnace. In these plates a number of cones are shown where very satisfactory tests were obtained, while others show no sign of having fused. In some cases the cones had a tendency to swell and lose their shape, especially if they were heated rapidly. They would often swell and crack near the base and then would have to be tested again and heated very slowly. This was a very common occurrence in the case of the poorer grades of clay. A number of the results shown here illustrate this point very nicely.

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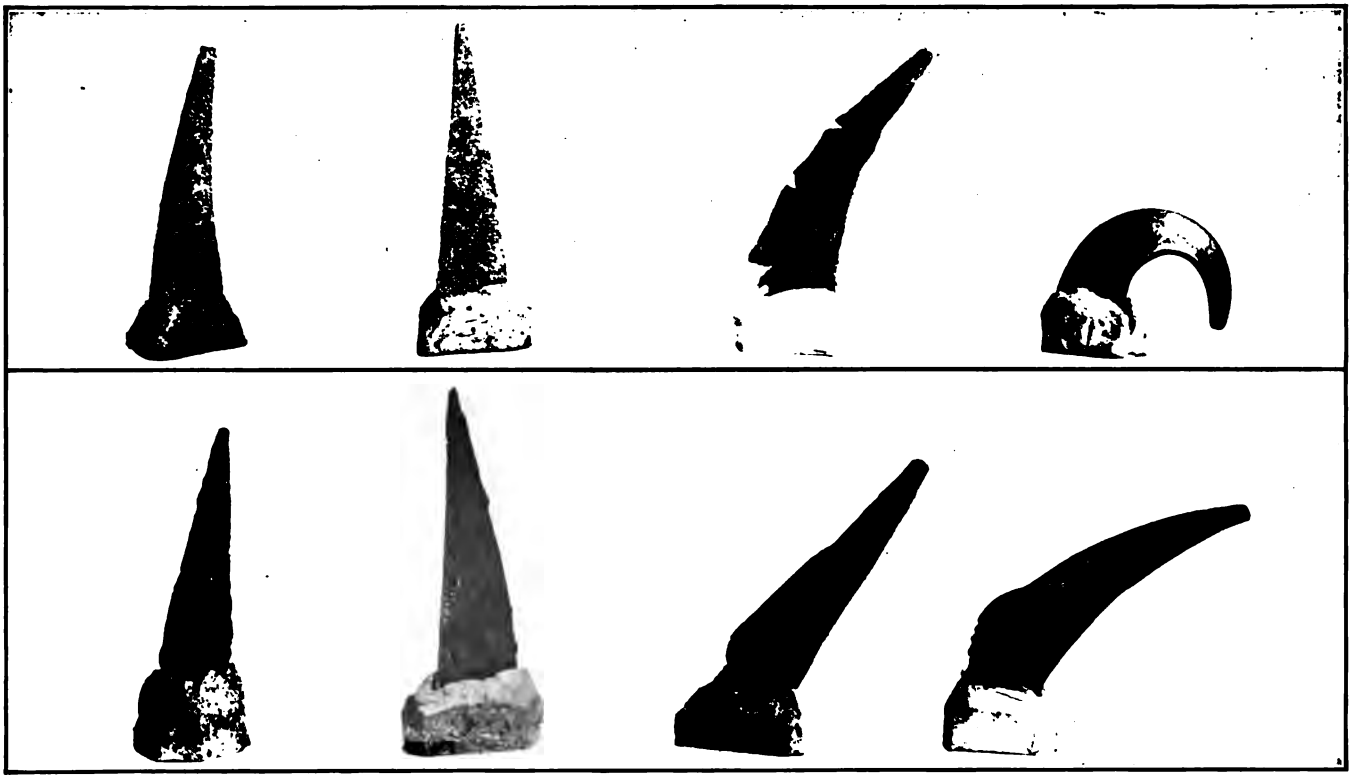
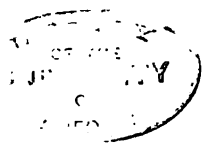
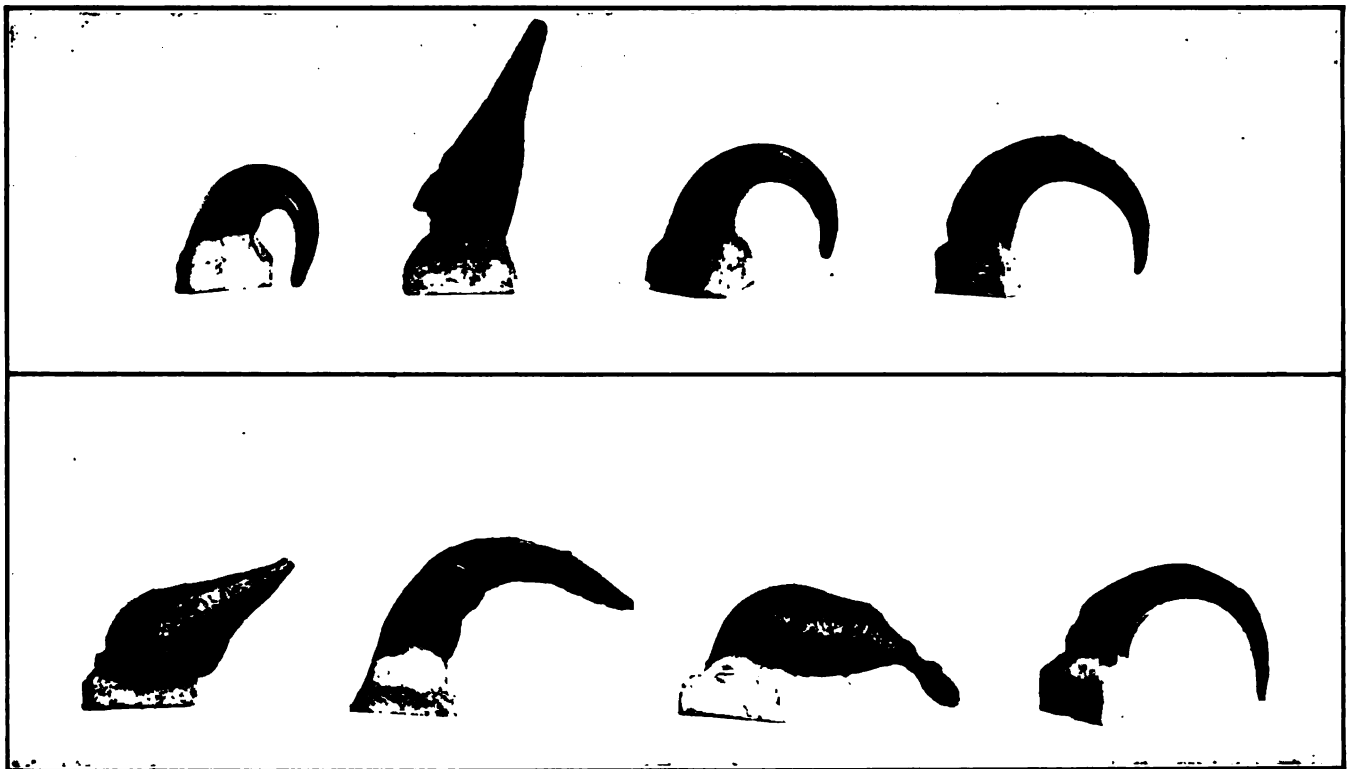


CLAY CONES, SHOWING RESULTS OF FUSION TESTS





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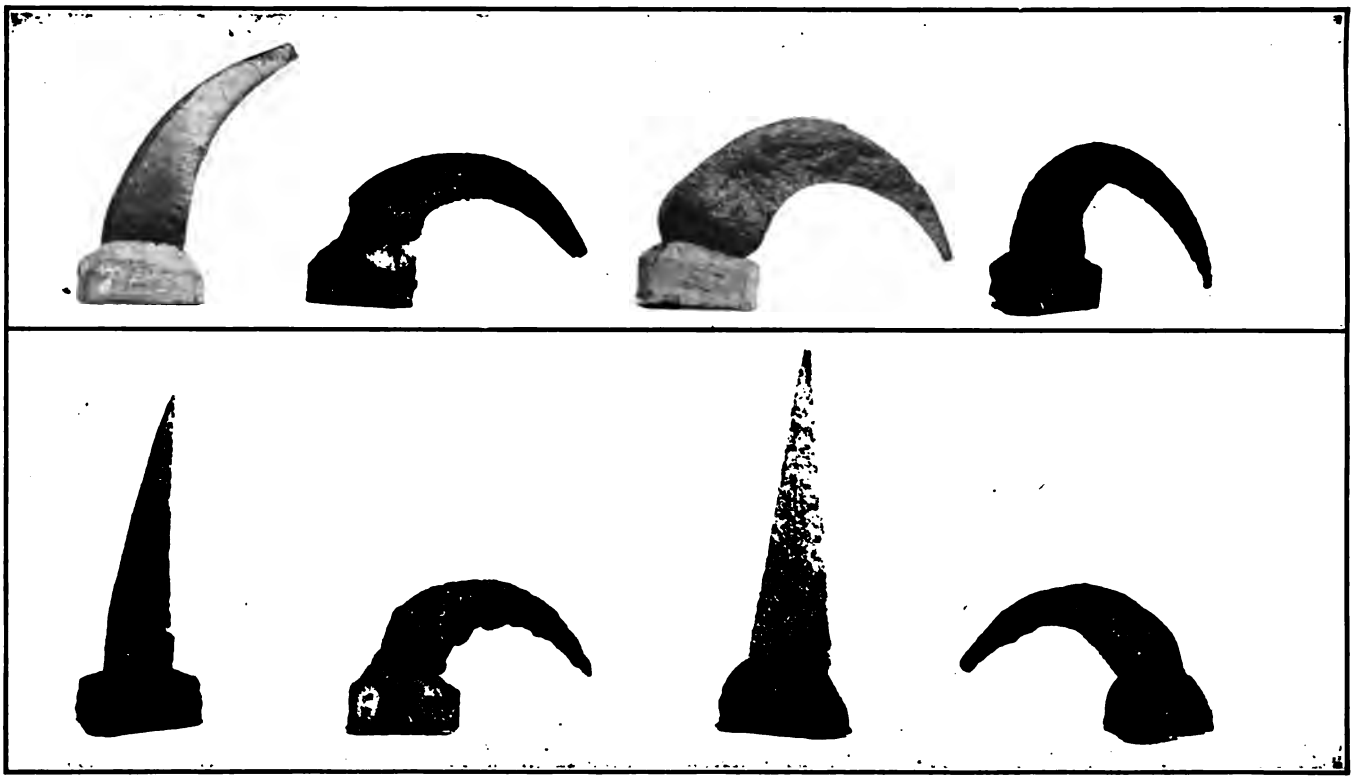

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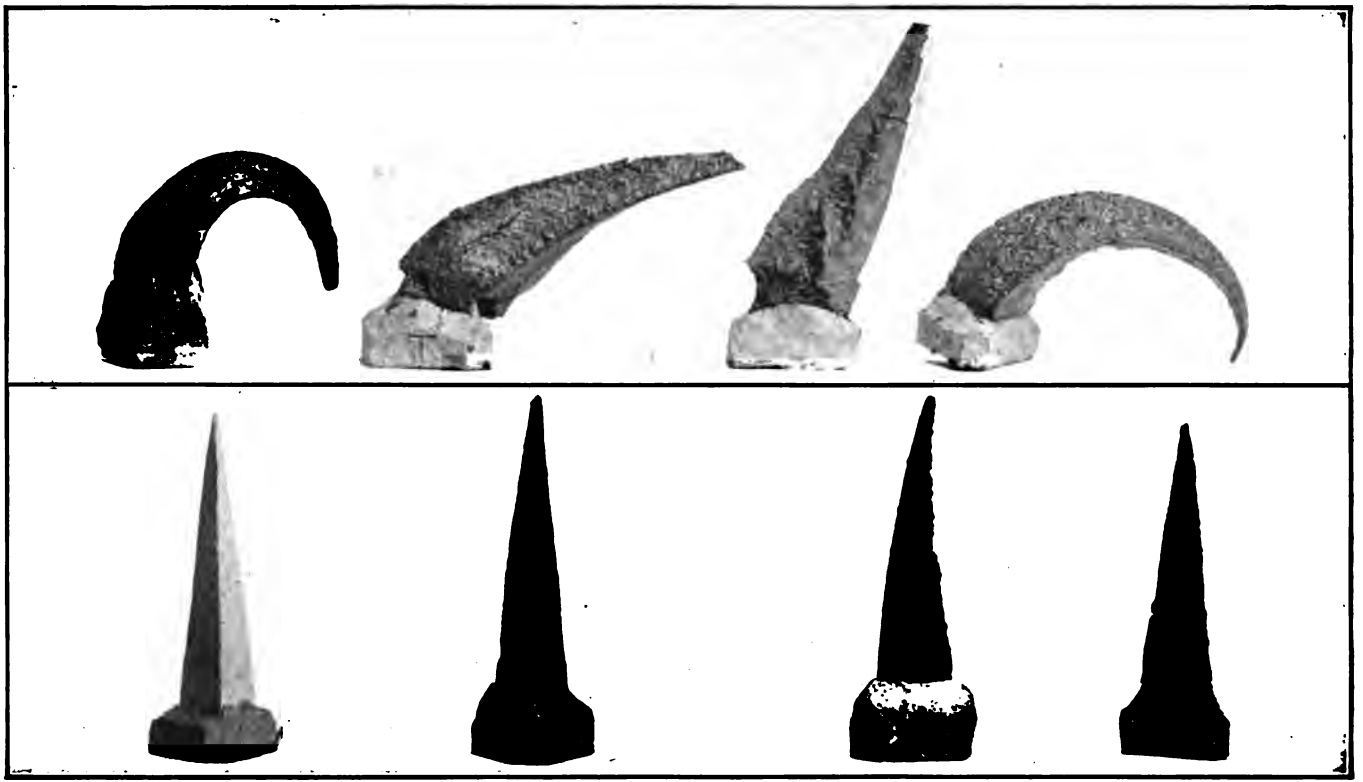

CLAY CONES, SHOWING RESULTS OF FUSION TESTS

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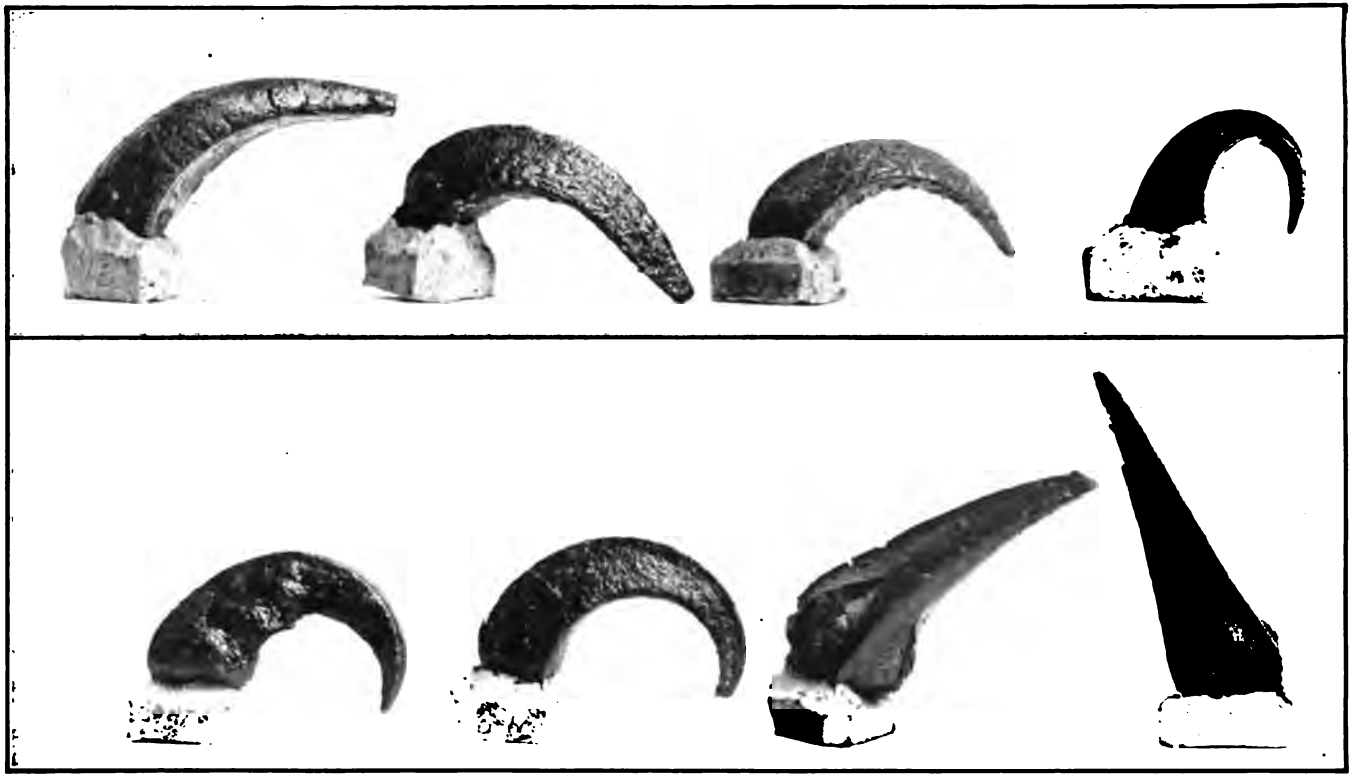

CLAY CONES, SHOWING RESULTS OF FUSION TESTS

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APPENDIX A

CHEMICAL ANALYSES

CHEMICAL ANALYSES.

Most of the chemical analyses of the clays of Washington given in this report were made by Mr. W. R. Bloor, of the Department of Chemistry of the State College of Washington.

In a few cases analyses have been copied from published reports, and in each case of this kind due credit will be given in connection with the analysis. The following outline of the methods used in making these analyses was prepared by Mr. Bloor.

METHODS EMPLOYED IN CLAY ANALYSIS.

I. *Method of Sampling.*—The clay which has been previously thoroughly air-dried in the laboratory, is broken up in a rubber sheet on the floor into pieces the size of a hazlenut. After thoroughly mixing it is quartered, the quarter broken up finer and again mixed and quartered. This operation is repeated with intermediate grinding until a sample weighing about 100 grams is obtained. This is ground in an agate mortar until it will all pass through a 100 mesh sieve. After thorough mixing on a piece of glazed paper a sample of about 50 grams is obtained by taking a small portion from various parts of the pile. The samples are stored in stoppered glass bottles for use. All samples required for one analysis are weighed out at one time.

II. *Moisture.*—Loss at 110 deg. C.* One gram of the sample is weighed into a platinum crucible of known weight and heated in an air oven for one and one-half hours at 110 deg. C. After cooling it is weighed and the loss is reported as moisture.

III. *Combined Water and Volatile Matter.*—Loss on ignition. The sample from II. is covered and heated over a Bunsen flame for one-half hour and then over a blast for from thirty to forty minutes, or until the weight is constant. The loss in

*Am. Jour. Sci., 3d Ser., Vol. XLVIII, 1894, p. 31.

weight consists of combined water and organic matter, carbon dioxide, etc.

When, as in many cases, it is desirable to weigh the water alone, the method of Brush and Penfield* has been found very satisfactory.

IV. *Silica, Separation from Alumina, etc.*—One gram of clay and six grams of dry sodium carbonate are ground together in an agate mortar, resting on a piece of glazed paper, until thoroughly mixed. This is now added to one-half gram of KNO_3, depending on the amount of iron present, and is lightly mixed with the rest. The whole is transferred to a small square of glazed paper and thence to a platinum crucible which it should fill not more than two-thirds full. The mortar is rinsed out with a little more carbonate and this used as a cap for the mixture in the crucible. The crucible, covered with the lid, is heated with a Bunsen burner gently at first and later with the full heat, adjusting the crucible so that the flame does not completely envelope it, but extends about two-thirds of the distance up the side. It may now be left to itself without fear of boiling over until fusion is complete. When all is quiet in the crucible, a strong blast is applied for about fifteen minutes longer with the flame directed against the side of the crucible. During this latter period of heating it is of advantage to remove the crucible with the tongs, and by careful rotation distribute the cooling mass over the side, in this way incorporating any unfused portions which may have struck to the sides of the crucible. It is again fused and heated a short time while the evaporating dish is being made ready to receive it. A platinum dish is best but with the precaution mentioned below a porcelain dish has been found quite satisfactory. One is selected of about six inches in diameter and carefully cleaned until when held opposite a good light it will show no roughness or dullness over the whole surface. It is rinsed out and filled with distilled water to within two cm. of the top. The lid of the crucible is dropped in and the crucible itself, cooled in the following

*Zeitschr. Anorg. Chemie, Vol. VII, 1894, p. 22.

manner: The rim is seized with the tongs and carefully rotated so as to distribute the melt as it cools as much over the sides and as little on the bottom as possible. As soon as it has solidified it is carefully dipped into cold water and moved around through it until it is cold. If this is properly done no water will get into the crucible and the top of the tongs will not be allowed to touch the water. By this treatment it is in excellent condition for removal after soaking up with water. In the sudden cooling the thin sheet of fusion is filled with fine cracks and it readily breaks apart when put into water. It is now placed into the evaporating dish and removed to the hot plate to soften.

In about a half hour it may be readily loosened from the crucible with a blunt glass rod. The platinum crucible and cover are cleansed as thoroughly as possible with hot water and then placed in a small beaker with dilute hydrochloric acid. To the covered evaporating dish there is now added concentrated hydrochloric acid in small portions until effervescence ceases and the liquid has a permanent yellow color.*

The evaporating dish to which has been added the washings from the crucible and cover is now removed to the hot plate and raised to boiling to expel CO_2. The cover is washed with hot water and the whole evaporated to dryness on the hot plate or on a water bath. The dry mass is thoroughly moistened with concentrated HCl and allowed to stand a few minutes. Water is added and the whole allowed to come to a boil with occasional stirring. It is filtered, the evaporating dish cleaned thoroughly with hot water and the precipitate washed until the wash water shows no yellow color. The filtrate and washings are returned to the evaporating dish and the process of evaporation and filtration is repeated in order to secure a good separation of silica. The two precipitates are washed with silver ni-

*NOTE: If manganese is present in the clay it may often be recognized and its quantity approximately determined at this point. The fusion has more or less of a bluish green color and when it is dissolved in water it gives it the same color. On addition of the first small amount of HCl this bluish green color changes to an evanescent pink from the permanganate formed and the depth of this pink color will give an idea of the amount of manganese present.

†Chem. Eng. Vol. I, p. 19.

trate solution until the washings give no color. The combined filtrate and washings are concentrated if necessary to 300 c. c. for the iron and alumnia precipitation.

After the second silica evaporation care must be taken to remove all adherent silica from the evaporating dish. This can in most cases be done by scrubbing with a rubber "policeman" and hot water. It must be continued until the surface of the dish is smooth and shining as in the beginning. If this treatment does not suffice the method suggested by Dr. F. L. Kartright† has been found satisfactory. The dish is boiled for three hours with dilute ammonia solution, filling the dish to about 1 cm. from the top and replacing the liquid as it boils away; then neutralizing with HCl, evaporating, separating and weighing the silica in the usual way. The weight of the silica obtained, corrected by volatilization with a little hydrochloric and sulphuric acids, is added to the main portion.

The washel silica precipitates are folded in their filter papers, transferred to a platinum crucible and carefully ignited with a Bunsen burner until the filter is burned away and all danger of loss by snapping is past. The silica is then heated to constant weight with a good blast. A correction is made at this point for impurities in the silica by volatilizing it with hydrofluoric and sulphuric acids in the following way: Moisten the precipitate with water, add a few drops of concentrated sulphuric acid and then hydrofluoric acid in small portions until the crucible is one-third full. Heat at a very low temperature till dry, ignite strongly and weigh. Deduct the weight of the residue from the total weight of the silica and add to the weight of ferric oxide and alumina, which may be conveniently ignited in the same crucible.*

The amount of the impurity is greater if the solution, in the first and second evaporations, is heated for a time at a temperature much above 125 deg. C.

*NOTE: In order to test the correctness of the procedure at this point, a systematic analysis of about 30 of these silica residues was made with the result that, although almost without exception calcium and magnesium were found to be components of the residues, they were present in such small amounts as to be negligible.

V. *Iron, Alumina, etc.*—The separation and determination of these substances was found to be best accomplished by a double precipitation, first by the basic acetate method and later by the ammonia method. The cold solution from IV. which had been previously concentrated to about 300 c. c. and oxidized with a few drops of nitric acid is treated in a large covered beaker with solid sodium carbonate until the first appearance of a reddish brown color. Then a solution of the same salt in water is added, drop by drop until the precipitate which is formed is not dissolved by vigorous stirring. This precipitate is dissolved by the addition of one or two drops of hydrochloric acid and two or three grams of sodium acetate, dissolved in a little water, is added. The beaker is placed over a flame and its contents brought to boiling. The boiling is continued for two or three minutes and the precipitate is allowed to settle. It is filtered first by decantation and washed two or three times with hot water containing a trace of sodium acetate to prevent a turbid filtrate. The precipitate is transferred to the original beaker by means of a stream of hot water, dissolved with the aid of heat, in as little HCl as possible and diluted with water to about 200 c. c. It is oxidized with two or three drops of HNO_3 boiled and precipitated by the addition of a not too great excess of NH_4OH. The boiling is continued for ten or fifteen minutes and then the precipitate is allowed to settle. It is filtered through the original filter and washed with hot water to absence of chlorides. The precipitate is removed as completely as possible from the filter and ignited, the filter being separately ignited and added to the main portion. Heat is applied gently until all danger of loss from sputtering is past and then strongly with the blast to constant weight, allowing free access of air to the crucible.

The above method has been found preferable when iron is present in fairly large amounts and manganese in more than traces. When iron is present in small amounts and manganese is absent, double precipitation with ammonia in the presence of ammonium salts is preferable since alumina is probably more completely precipitated.

VI. *Determination of* Fe_2O_3.—The precipitate of Fe_2O_3, Al_2O_3, etc., is treated with seven grams of potassium pyrosulphate and carefully heated until the whole is dissolved. In order to tell when this is accomplished the crucible is removed to a good light and allowed to cool. At one point in the cooling the liquid becomes transparent and particles of undissolved precipitate may be readily seen. After solution is complete the fusion is cooled and while cooling is spread over as much of the crucible as possible. Since it is often desirable to determine how much silica is present as an impurity in the alumina precipitate, the cooled mass is now dissolved in dilute sulphuric acid and evaporated to a thick paste on a water bath and then over a flame to fumes of sulphuric acid in order to render the silica insoluble. On boiling with water the silica is left as an insoluble residue which is filtered off, washed, ignited, corrected by volatilization with HF and its weight added to that of the main portion and deducted from the iron and alumina.

The filtrate which is strongly acid with sulphuric acid is transferred to a flask fitted with a Bunsen valve and reduced with a weighed amount of finely granular zinc. The reduction takes place rapidly and as soon as the zinc is dissolved the flasks are cooled and the solution titrated with standard potassium permanganate solution. The reading is corrected for the amount of impurities in the zinc used.

VII. *Titanium,* TiO_2, *Colorimetric Method.*—This method consists in comparing the depth of color produced by oxidizing the solution to be tested with hydrogen peroxide, with that of a standard titanium solution containing conveniently one centigram of TiO_2 as sulphate in ten c. c. which has been similarly oxidized. The comparison may be readily made with the solution which has just been titrated for iron. At this point it should not exceed 250 c. c. It is poured into a 300 c. c. flask, made up to the mark with water, thoroughly mixed and 100 c. c. filtered off for the test into a Nessler tube, five to ten c. c. concentrated H_2SO_4 is added, three c. c. of hydrogen peroxide and the whole mixed by inverting two or three times. The standard solution is prepared by filling another Nessler tube

with water adding sulphuric acid and H_2O_2 as before and running in the titanium solution from a burette until, when the thoroughly mixed solutions in the two tubes are adjusted to the same depth, the shades of color are the same.*

VIII. *Calcium, CaO.*—This is best done in a volume of 250 c. c. The strongly alkaline solution is raised to boiling and ammonium oxalate added in small portions so as not to interrupt the boiling until precipitation is complete. The boiling is continued with stirring until the precipitate becomes granular and settles readily. It is now filtered, washed once or twice with water, dried and strongly ignited in a platinum crucible. It is moistened with water and dissolved in dilute HCl and returned to the original beaker, the sides of which are carefully washed with the acid liquid. Precipitation is carried out again as above, the precipitate washed and ignited to constant weight, weighing as soon as cool.†

IX. *Magnesium, MgO.*—The combined filtrates from VIII. concentrated to about 250 c. c. and cooled are treated with sodium ammonium hydrogen phosphate (microcosmic salt) in decided excess and with NH_4OH in not too great excess. Continued stirring with a rubber tipped glass rod materially aids precipitation, but if the amount is small it is best left over night. The precipitate is removed to a filter and washed two or three times with dilute ammonia solution then dissolved on the filter with warm dilute hydrochloric acid solution using as little as possible. The second precipitate is made as before in small bulk of solution, using more ammonia and allowing to stand for some time. The precipitate is filtered and washed as before, wrapped in its filter paper, transferred to a platinum crucible and gently heated until the paper has burned away (it must not be allowed to ignite). Finally a weak blast is applied to

*NOTE: Experience in the laboratory has shown that the best results are obtained when not more than five c. c. of the standard titanium solution is used, since if more than this is needed the colors are too strong to be readily compared. If this is found to be the case it is better to dilute the solution to be tested one-half.

†NOTE: Prolonged washing with hot water should be avoided owing to the quite appreciable solubility of the oxalate in hot water.

constant weight. (Weight of MgO=Wt. of $Mg_2P_2O_7$ X 0.36212).

X. *Manganese, MnO, Colorimetric Method.* — For the amounts found in the Washington clays the colorimetric method by ammonium persulphate was found most convenient.

Two solutions are needed, one of silver nitrate containing two grams of the salt per liter and one of manganese sulphate containing the equivalent of two milligrams of MnO in ten c. c.*

For the determination, one gram of clay is placed in a small platinum dish and decomposed by hydrofluoric and sulphuric acids until disintegration is complete. The HF is driven off by repeated evaporations with small portions of sulphuric acid and nitric acid free from chlorine and water added until as much of the residue as possible is brought into solution. It is filtered and if more than seventy-five c. c. should be concentrated to about that amount. To it is added ten c. c. of the silver nitrate solution for every milligram of metallic manganese and it is transferred to a 100 c. c. flask, filtering if there is any turbidity. There is now added about one gram of solid ammonium persulphate and the flask is placed on a hot plate or steam bath until the pink color begins to show. It may then be removed and when the color is fully developed placed in cold water.†

According to the depth of color there is now placed in another 100 c. c. flask, ten c. c. or some multiple of that amount, of the manganese solution, so that when fully oxidized the color may be greater than that in the test solution. The solution is oxidized with the silver nitrate and ammonium persulphate as before, made up to the mark, mixed and poured into a burette. Fifty c. c. of the solution to be tested are now measured off into a 100 c. c. Nessler tube and made up to 100 c. c. with water. Into a similar Nessler tube is run the standard solution from

*NOTE: This can be conveniently made by acidifying a standard permanganate solution, reducing by sulphurous acid and diluting to required strength.

†NOTE: Should a brown precipitate have formed during the oxidation (due to deficiency of the silver salt) it is brought into solution with a little sulphurous acid, more silver salt is added and the oxidation repeated, if need be, after the addition of more persulphate.

the burette until on dilution to 100 c. c. the shades of color in the two tubes may be the same.

XI. *Alkalies.*—J. Lawrence Smith method. One-half gram of clay is thoroughly mixed in a small agate mortar with its own weight of NH_4Cl. About three grams of calcium carbonate are added mixed with the other two substances and the whole transferred to a Smith crucible, in the bottom of which has been placed a layer of about one-half gram of calcium carbonate. Another half gram of carbonate is used to rinse out the mortar and used as a cap for the charge. The cover of the crucible is put on loosely and the crucible inserted in a hole in a piece of stout asbestos board clamped in a vertical position. Heat is now applied with a small flame placed some distance below the crucible until the odor of ammonia ceases to be given off. The crucible is then lowered, the flame gradually increased and finally two burners at full flame are placed under it and the heating continued for about forty-five minutes. It is well to turn the crucible over two or three times during the heating, to prevent the mass sticking to the side. When the heating is complete the sintered mass is detached from the crucible by gentle tapping, or by softening with hot water, and digested in a small evaporating dish with hot water until disintegration is complete. It is first washed by decantation and any lumps are broken up by a pestle, then transferred to a filter and washed thoroughly with hot water. Most of the calcium is separated by double precipitation with ammonia and ammonium carbonate at boiling heat. The combined filtrates are evaporated to dryness and the ammonium salts expelled by careful heating. The residue is taken up with a little water heated to boiling and the remainder of the calcium precipitated by ammonia and ammonium oxalate. The oxalate is filtered off and the filtrate evaporated to dryness in a platinum dish and gently ignited. The residue is moistened with hydrochloric acid to decompose any alkali carbonate that may have formed, again evaporated, ignited* and weighed as total alkalies (chlorides).

*NOTE: Ignition must be very gentle and continued until the white fumes cease to come off. At no time is the dish to be heated to more than a faint redness.

XI. (a) *Potassium.*—To the dissolved chlorides in a small porcelain dish an excess of platinic chloride solution is added and then evaporated on a water bath until the whole mass solidifies on cooling; 80 per cent. alcohol is then added and the mass allowed to digest with stirring for a few minutes. It is then filtered through a Gooch crucible and the whole thoroughly washed with alcohol, dried at 100 deg. C. and weighed. (Factor K_2PtCl_6 to 2KCl is 0.307 and K_2PtCl_6 to K_2O is 0.19395).

XI. (b) *Sodium.*—The weight of potassium found is calculated to KCl and subtracted from the total chlorides. The remainder is taken as NaCl and calculated to Na_2O (NaCl to Na_2OX0.53077).

XII. *Sulphur.*—Determined by fusion of a separate portion of clay with sulphur-free sodium carbonate and a little nitre. After thorough disintegration of the mass with water, to which a drop or two of alcohol has been added to reduce and precipitate manganese, the mixture is filtered and washed with water containing sodium carbonate. Sulphur is precipitated from this in the usual way by acidulation in HCl and addition of excess of barium chloride at boiling point and estimated as usual.

XIII. *Phosphorus.*—The sample is prepared as for sulphur. After acidulating the filtrate with HNO_3 it is evaporated to dryness to separate silica, taken up with water, filtered, the separated silica ignited, volatilized with hydrofluoric and sulphuric acids and the soluble residue added to the main portion. To the solution, acid with HNO_3, is added considerable ammonium nitrate and the phosphorus precipitated with ammonium molybdate. Filter, wash, and dissolve the precipitate in dilute ammonia. From this solution the phosphorus is precipitated as ammonium magnesium phosphate by magnesia mixture, ignited and weighed as $Mg_2P_2O_7$ ($Mg_2P_2O_7$X0.63788= P_2O_5).

The purest obtainable reagents were used throughout the work, but it was found necessary to correct the results by running blank determinations with all reagents. The methods

outlined by Dr. W. F. Hillebrand in Bulletin 176 and 305 U. S. Geol. Survey, have been fully drawn upon and many thanks are due to Dr. Hillebrand for kind personal help in the course of the work.

Other references:

Wisconsin Survey, Bulletin VII.

Missouri Geological Survey, Vol. IX.

Reagents used:

$BaCl_2$. Saturated solution.

Ammonium Mollybdate. Dissolve 100 gm MoO_3 in 417 c. c. ammonium hydroxide. Pour this solution into 1250 c. c. HNO_3 (sp. gr. 1.20) with constant stirring.

Magnesia mixture. Dissolve 22 gm. calcined MgO in dilute HCl, avoiding excess of HCl. Then add excess of MgO and boil. Filter, wash once and add to the filtrate 280 gm. NH_4Cl and 700 c. c. NH_4OH (sp. gr. 0.96). Dilute to 2 liters.

H_2O_2=3 per cent. H_2O_2.

Sodium ammonium hydrogen phosphate.—Saturated solution.

Ammonium oxalate.—Saturated solution.

Platinic chloride.—10 per cent. H_2PtCl_6.

H_2SO_4. sp. gr. 1.84; HNO_3 sp. gr. 1.42.

HCl sp. gr. 1.18; NH_4OH sp. gr. 0.90.

The analyses given in the following table, except where otherwise indicated, were made by Mr. W. R. Bloor, of the department of chemistry of the State College of Washington.

TABLE OF CHEMICAL ANALYSES OF

	City	Material	Names of Factories
	BENTON COUNTY.		
1	Prosser	Brick clay	Prosser Brick and Tile Co
	CHELAN COUNTY.		
2	Chelan	Brick clay	H. E. Dunham
	COLUMBIA COUNTY.		
3	Dayton	Brick clay	E. L. Dexter
4	Dayton	Brick clay	E. L. Dexter
5	Dayton	Brick clay	E. L. Dexter
	DOUGLAS COUNTY.		
6	Bridgeport	Clay	Undeveloped, T. P. Hopp
	FERRY COUNTY.		
7	Republic	Brick clay	Undeveloped
8	Laurier	Slip clay	Undeveloped, L. C. Richardson
	KING COUNTY.		
9	Kummer	Flint fire clay	Denny-Renton Clay and Coal Co
10	Kummer	Flint fire clay	Denny-Renton Clay and Coal Co
11	Kummer	Flint fire clay	Denny-Renton Clay and Coal Co
12	Kummer	Sewer-pipe clay	Denny-Renton Clay and Coal Co
13	Kummer	Sewer-pipe shale	Denny-Renton Clay and Coal Co
14	Kummer	Silica sand	Denny-Renton Clay and Coal Co
15	Renton	Paving brick shale	Denny-Renton Clay and Coal Co
16	Taylor	Brick clay	Denny-Renton Clay and Coal Co
17	Taylor	Brick clay	Denny-Renton Clay and Coal Co
18	Taylor	Brick clay	Denny-Renton Clay and Coal Co
19	Taylor	Brick clay	Denny-Renton Clay and Coal Co
20	Taylor	Brick clay	Denny-Renton Clay and Coal Co
21	Taylor	Brick clay	Denny-Renton Clay and Coal Co
22	Taylor	Paving brick shale	Denny-Renton Clay and Coal Co
23	Auburn	Stoneware clay	Auburn Pottery Co
24	Auburn	Stoneware clay	Auburn Pottery Co
25	Auburn	Sand	Auburn Pottery Co
26	Seattle	Brick and tile clay	Seattle Brick and Tile Co
27	Seattle	Brick and tile clay	Seattle Brick and Tile Co
	KITTITAS COUNTY.		
28	Roslyn	Shale	Undeveloped
	LEWIS COUNTY.		
29	Chehalis	Brick and tile clay	Chehalis Brick and Tile Co
30	Sopenah	Brick and sewer-pipe clay	Little Falls Fire Clay Co
31	Sopenah	Brick and sewer-pipe clay	Little Falls Fire Clay Co
32	Centralia	Brick and tile clay	Wingard Bros
33	Centralia	Brick and tile clay	Wingard Bros
	LINCOLN COUNTY.		
34	Mondovi	Brick and tile clay	Undeveloped, H. T. Ahrens
	OKANOGAN COUNTY.		
35	Alma	Clay	Undeveloped, C. C. Parkman
36	Havilla	Clay	Undeveloped
	PIERCE COUNTY.		
37	Lagrande	Terra cotta clay	Denny-Renton Clay and Coal Co
	SAN JUAN COUNTY.		
38	Roche Harbor	Brick clay	Undeveloped
39	Roche Harbor	Brick clay	Undeveloped
40	Orcas Island	Brick clay	Undeveloped
41	Orcas Island	Brick clay	Undeveloped
42	Orcas Island	Shale	Undeveloped
43	Orcas Island	Shale	

NOTE: See References on p. 322.

WASHINGTON CLAYS AND SHALES.

	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric oxide (Fe_2O_3)	Lime (CaO)	Magnesia (MgO)	Potash (K_2O)	Soda (Na_2O)	Titanium (TiO_2)	Moisture (H_2O)	Combined Water Ignition	Miscellaneous	Total
1	54.92	18.56	6.48	1.34	1.14	1.76	1.14	1.50	5.28	8.04	MnO 0.10	100.21
2	59.84	16.40	4.10	5.84	0.36	1.62	2.84	1.20	0.74	5.51	§1.32	99.77
3	63.06	13.00	5.53	2.47	1.08	1.82	1.62	1.30	2.68	6.58	§1.06	100.15
4	63.25	15.34	5.91	2.34	1.26	1.50	1.31	1.20	2.63	3.96	§1.22	99.92
5	64.52	14.56	4.47	2.35	1.50	1.86	1.78	1.15	1.70	3.57	§2.58	100.01
6	62.50	16.85	5.09	5.20	2.55	3.26		.....	0.38	3.68	.....	99.51
7	60.13	29.10		†8.98	‡1.36	0.29		.....	.....	.....	(S) 0.75	*100.61
8	50.96	22.36	6.52	1.78	3.62	7.10		.....	2.24	5.70	.....	100.28
9	40.37	38.57	3.43	0.67	0.45	0.06	0.22	.....	1.56	15.30	.....	100.65
10	40.26	35.84	3.20	0.40	0.26	0.00	tr'ce	2.38	1.75	15.21	CO_2 0.70	100.00
11	33.44	45.23	1.57	1.60	3.61	1.44		.....	.....	16.44	.....	*103.33
12	63.90	19.42	5.75	0.88	1.80	1.81		.....	0.76	6.40	.....	100.72
13	61.56	17.46	6.69	0.40	1.37	2.80	0.78	0.65	1.16	7.00	.....	99.89
14	78.60	13.08	1.22	2.29	0.114	.....	.....	.....	3.80	.....	FeO 0.648	*99.252
15	62.11	17.59	4.77	1.53	2.26	2.30	1.65	0.51	1.63	5.60	.....	*99.95
16	62.42	17.98	4.34	1.34	1.84	2.78	1.56	0.66	1.44	5.74	.....	100.12
17	72.27	16.16	1.56	0.00	0.29	2.90	1.68	0.68	1.20	3.58	.....	100.32
18	68.98	15.56	4.90	0.50	0.36	2.30	1.64	0.34	0.18	5.54	.....	100.30
19	74.77	16.06	0.70	0.00	0.56	2.34	1.64	0.50	0.18	3.08	.....	99.83
20	72.30	19.95	0.71	0.52	tr'ce	2.98		.....	3.50		FeO 0.114	*100.074
21	41.36	40.49	0.71	0.62	tr'ce	1.47		.....	15.29		.....	*99.94
22	56.60	20.46	6.42	1.30	1.06	1.48	0.66	0.47	1.50	9.90	.....	99.82
23	62.80	23.04	1.14	0.40	0.51	3.84		.....	1.65	6.58	.....	99.76
24	66.69	21.01	1.14	0.33	0.32	4.20		.....	0.62	5.87	.....	100.18
25	81.40	10.65	1.90	0.50	0.18	3.00		.....	0.20	2.42	.....	100.24
26	58.96	16.57	6.10	2.37	2.97	0.83	3.24	1.15	3.53	3.86	MnO 0.65	99.78
27	60.80	18.44	6.00	3.17	1.34	1.32	2.90	0.40	2.10	3.29	.....	99.76
28	58.20	23.83	4.61	0.67	1.40	3.15		0.06	1.28	6.42	.....	99.62
29	58.75	18.27	3.86	0.86	1.68	2.18	1.53	0.85	2.12	8.66	MnO 1.20	99.96
30	55.82	19.43	2.38	1.13	0.46	0.80	0.95	1.15	7.72	7.82	MnO 2.04	100.00
31	59.86	19.43	5.15	1.40	1.70	0.38	0.32	1.15	2.78	6.48	MnO 0.61	99.26
32	60.10	16.61	8.55	1.43	1.29	0.80	1.18	0.98	3.04	6.60	.....	100.58
33	54.83	21.25	7.00	0.80	1.04	0.69	0.36	1.06	5.30	7.62	.....	99.95
34	60.52	19.37	5.95	1.94	1.65	1.99		.....	4.02	4.74	.....	100.18
35	62.62	19.14	3.26	5.15	2.79	3.07		.....	0.48	3.46	.....	99.97
36	65.66	16.66	6.56	3.10	3.76	tr'ce	0.71	.....	.....	3.40	.....	*99.86
37	67.24	19.23	2.50	0.34	0.49	0.88	.....	0.25	2.12	6.66	.....	99.79
38	55.81	26.28		†4.34	‡3.39	3.98		.....	.....	6.11	(S) trace	*99.91
39	56.35	24.62		†3.66	‡2.58	3.94		.....	.....	7.52	(S) 0.31	*99.98
40	57.30	21.40		†5.10	‡3.10	2.10		.....	.....	.....	(S) 0.50	*89.50
41	58.20	23.90		†6.3	‡4.10	2.90		.....	.....	.....	(S) 0.80	*91.20
42	62.80	19.20		†10.2	‡0.90	.....		.....	.....	.....	.....	*93.10
43	39.80	21.62		†29.1	‡2.91	2.15		.....	.....	.....	(S) 0.41	*95.99

NOTE: See References on p. 322.

CHEMICAL ANALYSES.—*Continued.*

	City	Material	Names of Factories
	SKAGIT COUNTY.		
44	Baker	Brick and tile clay	Washington Portland Cement Co...
45	Baker	Brick and tile clay	Washington Portland Cement Co...
46	Alger	Brick and tile clay	Bellingham Brick and Tile Co.....
47	Prairie	Clay, not used	Undeveloped, M. M. Clothier.....
48	Baker	Clay	Washington Portland Cement Co...
49	Jackman Creek	Clay	Undeveloped
50	Sauk	Clay	Undeveloped
	SNOHOMISH CO.		
51	Granite Falls	Clay	Undeveloped
	SPOKANE COUNTY.		
52	Mica	Sewer-pipe clay	Washington Fire Brick Co.....
53	Mica	Sewer-pipe clay	Washington Fire Brick Co.....
54	Mica	Sewer-pipe clay	American Fire Brick Co.....
55	Spokane	Brick clay	Undeveloped, W. G. Lake.....
56	Deer Park	Clay	Undeveloped
57	Freeman	Brick clay	Washingt'n Brick, Lime & Mfg. Co.
58	Freeman	Silica	Washingt'n Brick, Lime & Mfg. Co.
59	Cheney	Brick and tile clay	Undeveloped
60	Latah	Clay	Undeveloped, Lloyd C. White.....
61	Chester	Sewer-pipe and fire clay	Bergman Clay Manufacturing Co..
62	Chester	Sewer-pipe and fire clay	Bergman Clay Manufacturing Co..
63	Chester	Sewer-pipe and fire clay	Bergman Clay Manufacturing Co..
64	Trent	Clay	Undeveloped
65	Freeman	Brick clay	Washingt'n Brick, Lime & Mfg. Co.
66	Freeman	Sewer-pipe and brick clay	Washingt'n Brick, Lime & Mfg. Co.
67	Chester	Brick clay	Bergman Clay Manufacturing Co..
68	Mead	Brick clay	G. T. Davis
69	Spokane	Brick shale	A. T. Dishman
	STEVENS COUNTY.		
70	Clayton	Brick clay	Washingt'n Brick, Lime & Mfg. Co.
71	Clayton	Terra cotta clay	Washingt'n Brick, Lime & Mfg. Co.
72	Clayton	Terra cotta clay	Washingt'n Brick, Lime & Mfg. Co.
73	Clayton	Brick clay	Washingt'n Brick, Lime & Mfg. Co.
74	Clayton	Brick clay	Washingt'n Brick, Lime & Mfg. Co.
75	Clayton	Stoneware clay	Spokane Pottery Co
76	Clayton	Stoneware clay	Spokane Pottery Co
77	Clayton	Stoneware clay	Spokane Pottery Co
78	Bossburg	Slip clay	Spokane Pottery Co
79	Bossburg	Slip clay	Very little development
80	Portland	Brick clay	Pacific Portland Cement Co.....
81	Newport	Clay	Undeveloped
82	Newport	Clay	Undeveloped
83	Valley	Clay	Undeveloped
84	Northport	Clay	Undeveloped
85	Northport	Brick clay	Undeveloped
	THURSTON COUNTY.		
86	Olympia	Clay, not used	Undeveloped, G. W. Hopp.....
	WHATCOM COUNTY.		
87	Kendall	Clay, not used	Undeveloped
88	Kendall		Undeveloped
89	Sumas	Clay	Undeveloped
90	Sumas	Clay	Undeveloped
91	Sumas	Clay	Undeveloped
	WHITMAN COUNTY.		
92	Palouse	Stoneware clay	Palouse Pottery Mfg. Co.....
93	Palouse	Stoneware clay	Palouse Pottery Mfg. Co.....
94	Palouse	Stoneware clay	Palouse Pottery Mfg. Co.....
	YAKIMA COUNTY.		
95	North Yakima	Clay	Undeveloped, C. A. Rhodes.....

NOTE: See References on p. 322.

CHEMICAL ANALYSES.—*Concluded.*

	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric oxide (Fe_2O_3)	Lime (CaO)	Magnesia (MgO)	Potash (K_2O)	Soda (Na_2O)	Titanium (TiO_2)	Moisture (H_2O)	Combined Water Ignition	Miscellaneous	Total
44	58.75	25.94		†4.66	‡4.47	1.48		.....	.....	4.60	.....	*99.90
45	55.90	25.50		†4.90	‡2.83	3.91		.....	.....	6.45	(S) 0.51	*100.00
46	49.65	19.94	9.27	2.58	6.82	3.28		.....	2.15	5.85	.....	*99.04
47	56.04	22.56	8.70	0.45	3.87	3.18		0.11	0.30	4.96	.....	100.17
48	57.06	16.16	8.30	5.96	3.20	2.22		.....	.....	6.22	.....	*99.12
49	54.18	18.05	9.91	4.17	4.51	1.17	1.04	.....	.....	6.98	.....	*100.01
50	56.18	17.37	8.89	4.60	4.14	1.48	1.76	.....	.....	5.08	.....	*99.40
51	61.60	25.40		†7.20	‡2.80	2.94		.....	.....	.....	(S) 1.60	*101.04
52	75.04	19.18	0.76	.....	.....	0.45		0.15	0.86	4.54	.....	100.48
53	54.80	31.10	1.68	.....	tr'ce	0.21		0.23	2.70	9.40	.....	100.12
54	72.68	13.15	2.01	0.59	1.21	0.34	1.51	.....	8	49	.....	*99.98
55	67.16	19.26	3.26	0.47	1.13	1.63		.....	1.76	5.32	.....	99.99
56	51.22	33.52	1.72	.....	tr'ce	0.62		.....	1.38	11.16	.....	99.62
57	65.96	18.28	4.80	1.51	0.72	3.52		0.11	1.70	3.44	.....	100.04
58	73.58	17.29	1.78	tr'ce	0.32	0.40		0.04	0.86	5.44	.....	99.66
59	64.98	15.57	5.34	1.64	0.94	1.40	1.60	1.15	2.75	4.33	.....	99.70
60	73.33	15.54	2.00	0.64	0.44	1.74	0.76	0.30	0.90	4.48	.....	100.63
61	76.96	16.39	0.31	0.40	0.08	0.20	tr'ce	0.44	0.29	5.48	.....	100.55
62	52.32	30.68	1.70	0.80	0.46	1.50	tr'ce	0.52	1.76	10.08	.....	99.82
63	59.04	25.74	5.08	0.22	0.06	0.12	tr'ce	0.52	0.39	8.81	.....	99.98
64	71.28	17.46	1.80	0.40	0.05	2.74	0.28	0.70	5.50		.....	100.21
65	61.72	18.53	2.01	1.47	3.82	2.19	2.01	.....	8.81		.....	*100.06
66	59.92	16.65	8.25	2.22	3.71	2.14	2.02	.....	5.19		.....	100.10
67	58.13	19.01	6.84	2.06	3.17	2.08	1.51	.....	7.14		.....	*99.89
68	60.53	16.28	6.15	2.60	1.98	3.23	1.08	0.57	1.36	5.76	.....	99.49
69	59.59	18.93	4.69	0.83	1.14	3.10	0.34	0.65	2.20	8.94	.....	100.48
70	62.56	23.96	4.70	.....	tr'ce	1.12		.....	0.92	6.84	.....	100.10
71	53.64	31.96	1.82	.....	tr'ce	1.17		.....	1.66	10.06	.....	100.31
72	51.36	33.09	2.39	.....	0.78	0.08		.....	2.12	10.54	.....	100.36
73	65.80	18.78	5.42	.....	2.46	3.89		.....	1.88	3.14	.....	100.37
74	65.90	16.26	3.95	1.36	1.98	3.04	1.92	0.85	1.08	3.28	MnO 0.10	99.62
75	65.66	21.98	1.92	.....	0.80	0.80		.....	1.68	6.66	.....	99.60
76	58.06	29.04	1.82	.....	1.02	1.75		.....	1.18	7.56	.....	100.43
77	61.64	24.20	2.10	0.80	0.78	2.38	0.16	0.50	0.52	7.56	.....	100.14
78	52.94	22.12	6.72	2.99	3.91	4.62		0.06	1.56	4.98	.....	99.90
79	51.12	21.26	9.12	3.48	4.26	3.29		.....	1.34	5.70	.....	99.57
80	61.58	20.29	5.95	1.34	2.30	2.01		.....	1.94	4.14	.....	99.55
81	59.32	20.04	5.76	1.54	2.38	5.05		0.06	1.64	3.76	.....	99.50
82	74.23	19.08	1.07	tr'ce	0.54	0.47		.....	0.20	4.52	.....	100.06
83	69.12	23.40	0.96	tr'ce	0.92	0.15	0.17	.....	.....	4.94	.....	*99.66
84	56.72	15.69	9.34	4.43	3.13	1.19	1.09	.....	.....	6.64	.....	*98.23
85	59.76	17.29	5.71	2.94	4.11	1.51	1.81	.....	.....	6.86	.....	*99.99
86	57.36	18.79	6.68	3.89	2.42	1.06	0.10	0.50	3.56	3.58	.....	99.91
87	61.27	25.30		‡2.96	‡4.68	.....	.....	.....	.....	.....	.....	*94.21
88	57.06	26.80		†10.62	‡1.13	2.56		.....	.....	.....	.....	*98.17
89	48.70	32.10	4.90	0.90	0.30	tr'ce		.....	14.00	.....	.....	*100.90
90	69.31	12.37	2.11	0.57	0.54	2.08		.....	5.93	6.74	.....	*99.60
91	47.84	35.14		1.29	0.20	.....	.....	.....	15.90	.....	.....	*100.37
92	46.13	37.36	2.20	0.65	0.64	.....	.....	.....	1.34	12.20	.....	100.52
93	58.77	30.28	1.60	0.34	tr'ce	0.08		.....	0.88	8.44	.....	100.39
94	53.16	30.08	1.88	0.43	0.24	1.50	0.09	1.50	1.70	9.76	.....	100.29
95	55.63	18.25	3.38	1.13	1.08	1.38	0.90	0.75	7.25	8.57	$0.97	99.74

NOTE: See References on p. 322.

*15 O. C. Todd, analyst.
*54 O. A. Thomle, analyst.
*26, 49, 50, 65-67, 82-85, A. A. Hammer, analyst.
*11, 14, 20, 21, Wash. Geo. Survey, Vol. 1, page 175.
*46 W. H. Fuller, analyst.
*7, 38-45, 51, 87, 88, from Bulletin, U. S. G. S., 285, pp. 378-381.
*48 E. M. White, analyst.
*89, 90, H. K. Benson, Dept. Chem., University of Washington, analyst.
*91 Arthur G. Smith, analyst.
†(CaCO$_3$)
‡(MgCO$_3$)
§2 (Cr_2O_3), (P_2O_5), (SO_3), (SrO), (BaO), (ZrO_2), (V_2O_5)—1.32.
§3 (Cr_2O_3) 0.04, (P_2O_5) 0.25, (SO_3) 0.15, (SrO) 0.40, (BaO) 0.04, (ZrO_2) 0.19, (V_2O_5) 0.06.
§4 (Cr_2O_3) 0.09, (P_2O_5) 0.17, (SO_3) 0.42, (SrO) 0.16, (BaO) trace, (ZrO_2) 0.19, (V_2O_5) 0.12.
§5 (Cr_2O_3), (P_2O_5), (SO_3), (SrO), (BaO), (ZrO_2), (V_2O_5)—2.58.
§95 (Cr_2O_3) 0.11, (SO_3) 0.42, (SrO) 0.13, (BaO) 0.06, (ZrO_2) 0.18, (V_2O_5) 0.10.

APPENDIX B.

The following table compiled from Mineral Resources of the United States, U. S. Geological Survey, Washington, D. C., gives the statistics of clay products in the state of Washington from 1895 to 1908 inclusive, and will be of interest to those who desire to compare the growth of the industry in the state not only as a whole but also the different phases of it.

CLAY PRODUCTS OF WASHINGTON

FROM 1895 TO 1908.

Product	1895	1896	1897	1898	1899
Brick:					
Common—					
Quantity	14,865,000	10,164,000	14,887,000	21,845,000	55,794,000
Value	$84,305	$55,758	$86,607	$148,881	$405,678
Average per M	$5.67	$5.48	$5.84	$6.82	$7.27
Vitrified—					
Quantity	2,801,000	3,196,000	1,875,000	1,156,000	987,000
Value	$32,965	$31,500	$20,250	$14,777	$14,260
Average per M	$14.32	$9.85	$10.80	$12.78	$15.21
Front—					
Quantity	585,000	422,000	575,000	805,000	1,497,000
Value	$19,100	$8,390	$10,063	$13,200	$31,790
Average per M	$32.64	$19.88	$17.50	$16.40	$21.23
Fire—Value	$12,500	$8,300	$21,800	$23,250	$21,178
Drain tile—Value	$3,175	$3,700	$2,500	$3,605	$5,346
Sewer pipe—Value	$85,700	$47,000	$46,500	$43,300	$76,694
Architectural terra cotta—					
Value	$24,000	$1,100	*	*	*
Pottery:					
Earthenware and stoneware—Value	*	$1,180	$2,500	*	$13,350
Miscellaneous—Value	$3,700	$4,600	$3,090	$3,975	$22,986
Total value	$265,445	$161,528	$198,220	$250,998	$591,277
Rank of state	31	35	34	33	29
Per cent. of total clay products of United States	.41	.26	.32	.35	.62

* Included in "Miscellaneous."

CLAY PRODUCTS OF WASHINGTON—CONCLUDED.

Product	1900	1901	1902	1903	1904
Brick:					
Common—					
Quantity	55,671,000	61,595,000	73,825,000	72,825,000	87,782,000
Value	$404,687	$477,960	$577,407	$557,147	$665,878
Average per M	$7.27	$7 76	$7.87	$7.65	$7.59
Vitrified—					
Quantity	1,242,000	7,774,000	4,700,000	4,555,000	9,233,000
Value	$18,950	$139,162	$74,329	$67,314	$149,559
Average per M	$15.26	$17.90	$15.81	$14.78	$16.20
Front—					
Quantity	1,480,000	6,995,000	2,400,000	3,421,000	3,999,000
Value	$31,840	$147,881	$51,771	$65,757	$81,142
Average per M	$21.51	$21.14	$21.57	$19.22	$20.29
Fire—Value	$22,988	$24,542	$18,662	$18,932	$22,445
Drain tile—Value	*	$8,343	$7,649	$10,883	$8,812
Sewer pipe—Value	$119,807	$118,584	$118,462	$171,138	$215,282
Architectural terra cotta—					
Value	*	*	$35,225	*	*
Pottery:					
Earthenware and stoneware—Value	$9,430	$17,500	$13,354	$16,100	$22,000
Miscellaneous—Value	$17,757	$15,826	$43,597	$26,999	$45,801
Total value	$625,459	$944,798	$905,231	$928,265	$1,200,919
Rank of state	29	24	25	25	24
Per cent. of total clay products of United States	.65	.86	.74	.71	.92

Products	1905	1906	1907	1908
Brick:				
Common—				
Quantity	81,022,000	99,788,000	101,905,000	107,638,000
Value	$566,385	$706,968	$846,971	$817,962
Average per M	$6.99	$7.10	$8.31	$7 60
Vitrified—				
Quantity	9,768,000	9,609,000		
Value	$146,702	$156,476	*	*
Average per M	$14.72	$16.28	$18.22	$19.82
Front—				
Quantity	3,304,000	4,489,000	4,589,000	4,011,000
Value	$86,388	$122,770	$127,245	$112,749
Average per M	$26.15	$27.66	$28.08	$28.11
Fire—Value	$24,699	$46,525	$48,940	$42,045
Drain tile—Value	$11,153	$18,057	$17,025	$28,551
Sewer pipe—Value	$242,245	$313,880	$482,870	$493,165
Architectural terra cotta—Value	*	*	$94,795	$171,855
Pottery:				
Earthenware and stoneware—Value	$41,100	$41,560	$30,695	$20,601
Miscellaneous—Value	$59,860	$96,758	$278,393	$419,371
Total value	$1,175,032	$1,499,884	$1,921,984	$2,104,289
Rank of state	25	24	17	13
Per cent. of total clay products of the United States	.78	.98	1.21	1.58

* Included in "Miscellaneous."

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